Properties of kaon-photoproduction operator on nucleons and nuclei

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We discuss the properties of the transition operator for K^+ photoproduction on a free proton and for hypernuclear associated production. The main points discussed are (i) the relation between the operators in the pseudoscalar and the pseudovector-derivative coupling schemes; (ii) the theoretical uncertainties embedded in the tree-level operator; (iii) the nuclear-structure effects and uncertainties in the relativistic many-body model based on the Dirac equation with large scalar and vector potentials.

I. INTRODUCTION

The recent interest in the proposed electroproduction [(e,e′K^+) reaction][1] and photoproduction [(γ,K^+) reaction][2] of a K^+ meson on a nuclear system, thereby producing a hypernucleus, has resulted in a growing number of theoretical studies and publications,[1,2] as well as preliminary experimental plans and discussions.[3]

Of crucial importance in estimating cross sections for the electromagnetic production of hypernuclei is the basic transition operator, or *S*-matrix element, for $\gamma+p\to K^+ + \Lambda$. This operator is subject to large uncertainties. One such uncertainty, namely, the problem of the actual values of the coupling constants to be used in the calculation, has been pointed out in a previous publication.[1] However, the basic *properties of this bare operator,* as well as its *properties when embedded in the nucleus,* seem to be relatively unknown, despite their great importance in dealing with the production process. *The object of this note is to provide a handy reference to the properties of the transition operator both for the bare process and for nuclear applications.* The main questions to be discussed are the pseudoscalar (PS) versus pseudovector-derivative (PV) theories, and the role of nuclear effects, especially within the context of the relativistic nuclear models based on the Dirac equation in the presence of large scalar and vector potentials, or σ and ω mean fields. We shall also comment on some other questions regarding the assumptions behind the model used to construct the photoproduction operator.

Although we are aware of the fact that our discussion is, to a large extent, a recapitulation of existing knowledge, we are still convinced that it serves the very useful purpose of shedding some new light on the properties of the photoproduction operator. Hopefully, this will prevent some future misunderstandings and misconceptions prevailing in some of the current lore on the subject. Thus the motivation for this note is at least partly instructive (and it should be viewed as such by the reader); at the same time we believe that some of the discussion presented here is new.

II. PS AND PV COUPLING SCHEMES AND THE ELEMENTARY BARYON CURRENT

We start with a discussion of the meson-baryon-baryon vertices. It is well known that there are two possible ways of coupling the KYp vertex (in the context of an effective-Lagrangian theory): pseudoscalar (PS) and pseudovector derivative (PV). In the pseudoscalar theory the KYp vertex is described by the γ_5 operator and a coupling constant g_{KYp}. The resulting Feynman diagrams at the tree-level, obtained within an effective-Lagrangian approach,[4] are shown in Fig. 1. These consist of particle-exchange diagrams in the s (proton exchange), t (kaon exchange), and u (Λ and Σ^0 hyperons exchange) channels. In the pseudovector theory, the KYp vertex is described by

$$\frac{f_{KYp}}{m_0}\gamma_5 \not{t} ,$$

where $\not{t}=t\cdot\gamma$ and t is the outgoing kaon four-momentum. The mass scale m_0 is arbitrary, and only the combination f/m_0 has a physical meaning. The coupling constants are chosen such that the vertices in the two coupling schemes are identical for unbound particle lines. Using the free-particle Dirac equation for the proton,

$$\not{p}_N u_N(\mathbf{p}_N)=M_N u_N(\mathbf{p}_N) ,$$

and the hyperon,

$$\not{p}_Y u_Y(\mathbf{p}_Y)=M_Y u_Y(\mathbf{p}_Y) ,$$

it follows immediately that

$$\bar{u}_Y(\mathbf{p}_Y)\gamma_5\not{t}u_p(\mathbf{p}_N)=(M_Y+M_N)\bar{u}_Y(\mathbf{p}_Y)\gamma_5 u_p(\mathbf{p}_N) . \quad (1)$$

In these expressions, M_Y and M_N are the hyperon (Λ,Σ^0) and proton masses, while the Dirac spinors $u(\mathbf{p})$ are functions of the momenta. (Note that these relations will not be true for bound particles in a nucleus in the relativistic nuclear-structure model, where the large scalar and vector potentials are introduced in the Dirac equation.) The two coupling schemes will therefore be equivalent if

$$\frac{f_{KYp}}{m_0}=\frac{g_{KYp}}{M_Y+M_N} . \quad (2)$$

This result is reminiscent of the relation

$$f_{\pi NN}/m_\pi=g_{\pi NN}/2M_N$$

in the πNN sector. However, this relation for the pion

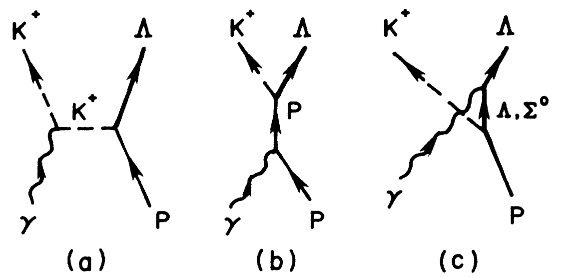

FIG. 1. Feynman diagrams for the elementary reaction $\gamma_v + \mathrm{p} \rightarrow \mathrm{K}^+ + \Lambda$ in the pseudoscalar theory.

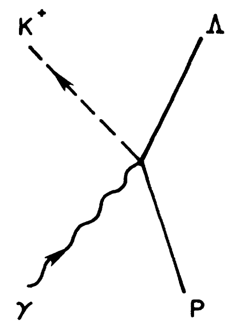

FIG. 2. The seagull, or contact term, that arises in addition to the particle-exchange diagrams of Fig. 1 in the pseudovector coupling scheme.

case could also be derived by demanding that the usual nonrelativistic reductions of the two possible vertex operators be identical. This will no longer be true for the KYp system, due to the difference in masses between the proton and the hyperon. While the PS yields the nonrelativistic reduction

$$g_{\mathrm{KYp}}\chi_{\mathrm{Y}}\sigma\cdot\left[\frac{\mathbf{p}_{\mathrm{Y}}}{2M_{\mathrm{Y}}}-\frac{\mathbf{p}_{\mathrm{N}}}{2M_{\mathrm{N}}}\right]\chi_{\mathrm{p}} ,$$

the PV result is

$$\frac{f_{\mathrm{KYp}}}{m_0}\sigma\cdot\mathbf{t} .$$

Thus, the two couplings are not equivalent if the usual nonrelativistic reduction is performed first.

In the PV coupling mode there is an additional diagram, the so-called seagull or contact term (Fig. 2). We note that although the graphical representation of the particle-exchange terms is unchanged, the expressions representing the contributions to the S matrix arising from each term do differ in the two coupling schemes.

The contributions of the magnetic moments are included phenomenologically using a Pauli-type term in the Lagrangian to represent the interaction of the electromagnetic field with the anomalous magnetic moment, μ_B, of the baryons. These contribute terms of the type

$$\mu_B\partial_v\bar{u}\sigma^{\xi v}u$$

to the electromagnetic current density (J^ξ). It has long been realized that these contributions should emerge as higher-order corrections to the perturbation calculations.[5] A complete theory along these lines has never been worked out; indeed, very similar words were written 37 years ago[6] under very similar circumstances. It is important, however, to keep in mind that the magnetic moments should not be treated as tree-level contributions in the strict theoretical sense.

An important observation is *the identity of the lowest-order* (in the coupling constant) *photoproduction S matrix in the pseudoscalar and pseudovector-derivative coupling schemes when all electromagnetic moments vanish.* These moments should be excluded from this discussion since, in the rigorous theoretical sense, they are part of higher-order contributions. This identity is easily verified from the explicit expressions for the S matrix in the two theories, using the Dirac equations and the energy-momentum relations for free particles. In particular, the kaon-exchange diagram [Fig. 1(a)] is identical in the two coupling schemes by virture of Eq. (1). The sum of the PV proton exchange diagram [Fig. 1(b)] plus the contact term (Fig. 2) is identical to the PS proton-exchange term. The u-channel diagram has contributions only from electromagnetic moments, which are excluded in the present comparison of the two coupling schemes. Thus, *the two theories are identical for free particles in the absence of electromagnetic moment contributions.* In fact, one theory can be obtained from the other as a result of an algebraic chiral gauge transformation.[7]

If the electromagnetic moment terms are included, the two theories differ by an amplitude arising from an equivalence-breaking term generated by the electromagnetic moment contributions.[8] In the present case, the corresponding contributions to the PS baryon current are

$$J^{\xi}_{\mu_{\mathrm{p},\Lambda,T}}=-\bar{u}_{\Lambda}(\mathbf{p}_2)\left[\frac{g_{\mathrm{K}\Lambda\mathrm{p}}\mu_{\mathrm{p}}}{(p_2+\mathrm{K})^2-M_{\mathrm{N}}^2}\gamma_5(K\!\!\!/+M_{\mathrm{N}}-M_{\Lambda})i\sigma^{\xi v}q_v+\frac{g_{\mathrm{K}\Lambda\mathrm{p}}\mu_{\Lambda}}{(p_1-\mathrm{K})^2-M_{\Lambda}^2}\gamma_5 i\sigma^{\xi v}q_v(K\!\!\!/+M_{\Lambda}-M_{\mathrm{N}})\right.$$
$$\left.+\frac{g_{\mathrm{K}\Sigma\mathrm{p}}\mu_T}{(p_1-K)^2-M_{\Sigma^0}^2}\gamma_5 i\sigma^{\xi v}q_v(K\!\!\!/+M_{\Sigma^0}-M_{\mathrm{N}})\right]u_{\mathrm{p}}(\mathbf{p}_1) . \quad (3)$$

In Eq. (3), μ_p and μ_Λ are the anomalous magnetic moments of the proton and the Λ hyperon, while μ_T is the $\Lambda\to\Sigma^0$ transition moment (governing the $\gamma\Lambda\Sigma^0$ vertex). The four-momenta of the photon, initial proton, and the final Λ and K^+ are q, p_1, p_2, and K, respectively. The corresponding contributions in the PV coupling scheme differ by

$$\delta J^{\xi}_{\mathrm{PV-PS}} = -\bar{u}_\Lambda(\mathbf{p}_2)\left[\frac{g_{K\Lambda p}\mu_p}{M_\Lambda+M_N}+\frac{g_{K\Lambda p}\mu_\Lambda}{M_\Lambda+M_N} + \frac{g_{K\Sigma^0 p}\mu_T}{M_{\Sigma^0}+M_N}\right]\gamma_5 i\sigma^{\xi\nu}q_\nu u_p(\mathbf{p}_1)\ , \tag{4}$$

where terms of order $(M_Y-M_N)/(M_Y+M_N)$ and higher have been suppressed. Using our standard[1] values for $g_{K\Lambda p}$, $g_{K\Sigma^0 p}$, μ_p, μ_Λ, and μ_T, we find that *the terms in large parentheses in Eq. (4) have the value of 10.87* in units of 10^{-3} $e/2M_N$ MeV. For comparison, *the corresponding numerical value for* (γ,π) (pion photoproduction) *is 0.85* in the same units. This simple estimate explains the big qualitative difference between the (γ,K^+) and (γ,π) operators: While the two coupling schemes (PS and PV) yield virtually the same results for the latter,[9] much larger differences are found between the two schemes for the former.[10,11] [Indeed, Ref. 11 tries to fit phenomenologically the available data for $\gamma+p\to K^++\Lambda$, and the authors find that they need very different sets of coupling constants for the PS and PV operators (differences are in the range of 20–30 %). Likewise, using the PS-fitted coupling constants in the PV operator would overestimate the data by a factor of 2–3, while the inverse procedure underestimates the data by 30–40 %. We note that the approach of Ref. 11 is to treat the couplings as phenomenological flexible parameters, to be readjusted in each new calculation. In such an approach, the theoretical basis of an underlying effective Lagrangian and field theory is absent, so one gives up the possibility of exploring higher-order corrections to the operator. In view of our discussion in this section, it is understood that the differences between the PS and PV operators, arising from the electromagnetic moment contributions, are part of those higher-order corrections.]

The baryon current, J^ξ, is gauge invariant in both coupling schemes when calculated as described here. In particular, each of the electromagnetic moments contributions is gauge invariant by itself ($q_\xi\sigma^{\xi\nu}q_\nu=0$ due to the antisymmetry of $\sigma^{\xi\nu}$). In the PS case the combination of the remaining two terms from the diagrams 1(a) and 1(b) is gauge invariant, while the addition of the seagull term (Fig. 2) is essential for gauge invariance in the PV case.

III. THEORETICAL UNCERTAINTIES IN THE TREE-LEVEL OPERATOR

It has been pointed out[1] that there is a substantial uncertainty regarding the values of the coupling constants $g_{K\Lambda p}$ and $g_{K\Sigma p}$ appearing in the S-matrix element. Values derived on the basis of the available photoproduction data, described by a production operator based on tree-level diagrams, largely differ from those obtained by other sources, namely, $g_{K\Lambda p}$ is approximately 65% larger in the latter case, while $g_{K\Sigma p}$ is much smaller.

Although the reason for these discrepancies is at present unclear, it is important to realize that the (γ,K^+) reaction is not necessarily a reliable source of information for determining the required coupling constants. This observation is a direct result of the Kroll-Ruderman theorem,[12] which states that photomeson production provides an unambiguous means of measuring the (renormalized) meson-nucleon coupling constant only if the meson mass is much smaller than the nucleon mass. More precisely, the matrix element for a charged meson photoproduction at threshold, correct to all orders in the meson coupling constant and in the limit of a vanishing meson mass, is equivalent to the weak-coupling result obtained from second-order perturbation theory. The K^+ meson has a rather large mass,

$$m_{K^+}/\tfrac{1}{2}(M_N+M_\Lambda)\simeq 0.48\ ,$$

and the product of the latter ratio with $g_{KN\Lambda}$ is also large. One cannot hope, therefore, to determine the coupling constants from the Born terms alone in the $\gamma+p\to K^++\Lambda$ case. By the same argument, a transition operator based on tree-level diagrams alone may not be enough. This observation is also supported to some extent by a study of $K^++N\to K^++N$ at threshold using the same theoretical techniques (see Appendix). The extent of necessary corrections to the coupling constants and the right way to extract such corrections using a phenomenological Lagrangian is at present unclear, however.

IV. RELATIVISTIC NUCLEAR STRUCTURE EFFECTS

In addition to nonrelativistic-nuclear-model predictions,[1,2] we have recently[13] studied the $(e,e'K^+)$ reaction using the fully relativistic transition operator and nuclear and hypernuclear wave functions containing Dirac-Hartree orbitals. (The latter are obtained from a relativistic nuclear structure model extended to hypernuclei.) In this section we present a critical discussion of the effects of the relativistic scalar and vector potentials and of the four-component wave functions on the cross sections. We shall be interested especially in the differences between the pseudoscalar and pseudovector theories.

Our present work is based on the relativistic σ-ω mean field theory (MFT).[14] We start with the MFT Lagrangian density for nucleons and Λ in the presence of a scalar mean field ϕ_0 and a vector mean field $V^\mu=(V_0,\mathbf{V})$ (note that $\mathbf{V}=0$ for applications to closed-shell nuclei or for nuclear matter calculations):

$$\mathcal{L}_{\mathrm{MFT}}=\bar{\psi}_N[\gamma_\mu(i\partial^\mu-g_v^N V^\mu)-(M_N-g_s^N\phi_0)]\psi_N + \bar{\psi}_\Lambda[\gamma_\mu(i\partial^\mu-g_v^\Lambda V^\mu)-(M_\Lambda-g_s^\Lambda\phi_0)]\psi_\Lambda + \text{purely mesonic terms}\ , \tag{5}$$

where the meson-baryon coupling constants for nucleons and hyperons may differ. The MFT equations for the baryon and meson fields in nuclear matter are obtained following the usual procedures.[14] The baryons acquire an effective mass

$$M_B^* = M_B - g_s^B \phi_0 \quad (B = \mathrm{N}, \Lambda) , \tag{6}$$

and the single-particle energies are shifted by the vector potential.

In the spirit of the relativistic MFT, the free-particle lines of Figs. 1 and 2 should be corrected for interactions with the medium through the vector and scalar fields. This picture yields medium-modified propagators as well as bound-baryon Dirac spinors. Denoting the free-baryon Feynman propagator by $G_0^B = (\not{p} - M_B)^{-1}$, and recalling that the scalar and vector potentials result in a self-energy

$$\Sigma_B = -g_s^B \phi_0 + g_v^B \not{V} , \tag{7a}$$

the medium-modified propagator G is obtained as a solution of $G_B = G_0^B + G_0^B \Sigma_B G_B$. This yields the many-body modified propagator

$$G_B = (\not{p} - M_B - \Sigma_B)^{-1} . \tag{7b}$$

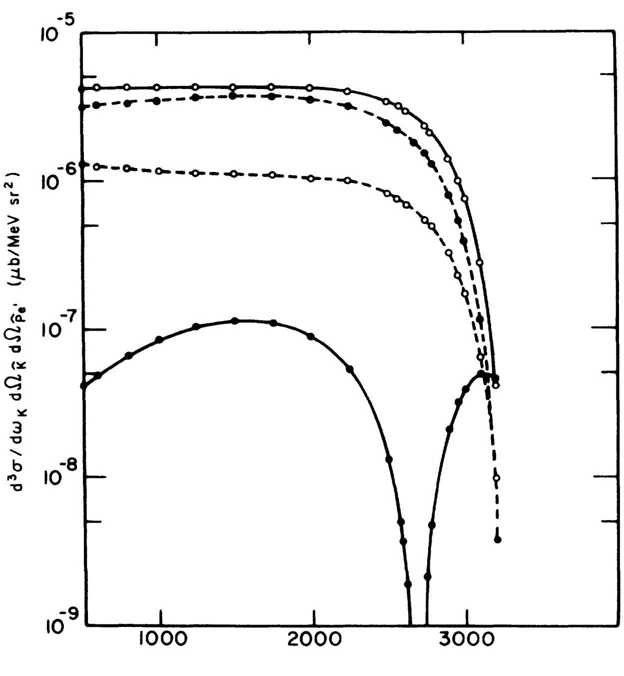

FIG. 3. PS cross sections for the $(\Lambda 1s_{1/2}, P1p_{1/2}^{-1})_{0^-,1^-}$ excitations in $^{16}_{\Lambda}$O. Results are shown for the "complete" calculation (full lines) and for the calculations with $\Sigma_B = 0$ in the propagators (dashed lines). The calculations have been carried out for incoming electron momentum of $p_e = 4$ GeV/c and outgoing electron and kaon angles of $\theta_{\hat{p}_e'} = 5°$, $\theta_{\hat{K}} = 5°$, and $\phi_{\hat{K}} = 0$. The results are shown as a function of the outgoing electron momentum p_e'. Full and open circles refer to $J^P = 0^-$ and 1^-, respectively.

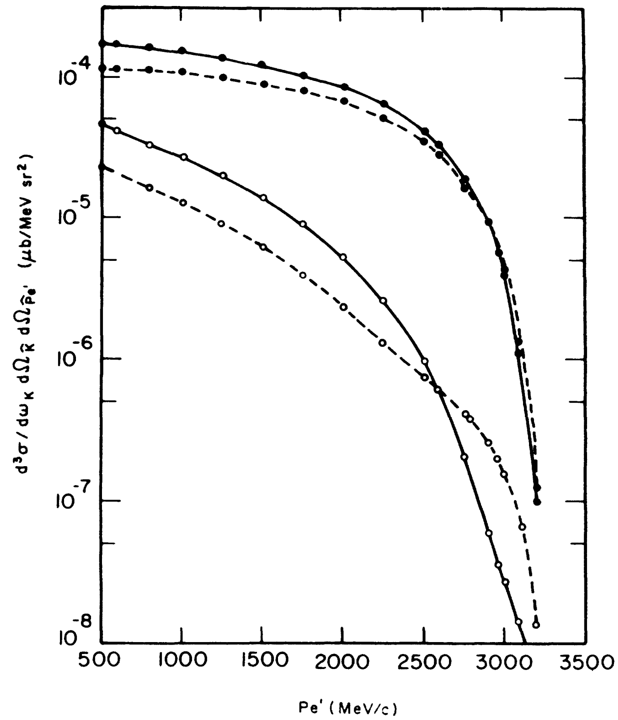

FIG. 4. As Fig. 3, but for the PV case.

In our calculations[13] we have modified the nuclear current accordingly. While using finite-nucleus Dirac-Hartree spinor *wave functions,* we approximate the medium-modified *propagators* [Eq. (7)] by using the constant nuclear matter values of the potentials. We have also used $\mathbf{V} = 0$: we remark upon this in the following.

The calculation of the cross section for the (e,e'K$^+$) reaction has been described in a recent publications.[13] Here we wish to elaborate on the differences between the PS and the PV results. In Figs. 3 and 4 we show two examples of calculated cross sections in the PS and PV theories, respectively. The "complete" calculations include the modified propagators [Eq. (7)], and are compared to the case where $\Sigma_B = 0$ in the propagator (but the single-particle wave functions are still those of a finite nucleus in the MFT).

The apparent large differences discovered here, following Cohen, Price, and Walker,[13] between the PS and PV couplings are a common feature in nuclear-reaction calculations adopting the Dirac nuclear structure approach when a pseudoscalar meson is involved. For example, Wallace[15] finds overly large potentials for proton-nucleus scattering as the proton energy approaches zero, but results based on pseudovector πN coupling may avoid this difficulty.[15] An interesting early study of this problem was reported by Miller and Weber.[16,17] They find large differences between the predictions of the PS- and PV-vertex calculations for the (p,π) reaction, and trace those directly to the role of the large relativistic self-consistent potentials which change the relation between the large and small components of the Dirac spinor. Subsequently, Friar[18] has shed more light on the difference between the PS and PV couplings in these relativistic approaches. For the pion and nucleon cases, πNN matrix elements in both PS and PV couplings should yield identical results with the exception of the scalar potential term (and, when dealing with electromagnetic processes, in the absence of electromagnetic moment terms, as discussed earlier). Denoting the pion wave function by $\phi(\mathbf{r})$ and the nucleon wave functions by $\psi_{N_f}(\mathbf{r})$ and $\psi_{N_i}(\mathbf{r})$ for the final and initial states, respectively, the matrix element for the πNN vertex operator (the pion has an outgoing momentum t) is

$$H_{fi}=\int d\mathbf{r}\psi^\dagger_{N_f}(\mathbf{r})\Gamma_{\pi NN}\phi(\mathbf{r})\psi_{N_i}(\mathbf{r}) \ .$$

In the PS case $\Gamma^{PS}_{\pi NN}=g\gamma^0\gamma_5$, while in the PV case $\Gamma^{PV}_{\pi NN}=g\gamma^0\gamma_5 \not{t}/2M_N$, and g includes the πNN coupling and the appropriate isospin Clebsch-Gordan coefficient (± 1 or $\sqrt{2}$). The equivalence-breaking term is a result of the strong scalar potential $U_s^N=-g_s^N\phi_0$:

$$H^{PV}_{fi}=H^{PS}_{fi}+\frac{g}{M}\int d\mathbf{r}\,\psi^\dagger_{N_f}(\mathbf{r})\gamma^0\gamma_5 U_s\phi(\mathbf{r})\psi_{N_i}(\mathbf{r}) \ . \quad (8)$$

The extra piece is a "seagull" diagram, shown in Fig. 5. The effect is large since the scalar potential is large, typically around $-0.5\ M_N$ for nuclear matter.

The situation is more complicated in our case. In addition to the scalar-potential equivalence breaking term, we also have an additional term proportional to the difference of the nucleon and hyperon vector potentials,

$$U_v^N-U_v^\Lambda=(g_v^N-g_v^\Lambda)V_0 \ .$$

This term arises because in the final state one deals with a Λ spinor. (In the case analyzed by Friar[18] this term vanishes since the same vector potential appears in the initial and final states.)[19] In dealing with K mesons and strange nuclei, it introduces new many-body effects. These effects are also large, since

$$U_v^N-U_v^\Lambda \simeq 0.5\ U_v^N \simeq 0.25\ M_N \ .$$

An important point emerging from our discussion is that, in the relativistic model, calculated (γ,K^+) and $(e,e'K^+)$ results are sensitive to the type of coupling adopted (PV or PS). This is just one facet of a general and deep problem in the relativistic nuclear structure model. The role of pseudoscalar mesons (pions, kaons, etc.) is an outstanding unsolved problem in the relativistic σ-ω renormalizable field theory of nuclear dynamics, quantum hadrodynamics (QHD).[14] A satisfactory relativistic Lagrangian containing pseudoscalar mesons has not yet been found,[14] and it is therefore impossible to construct a QHD-based reaction model that incorporates these mesons accurately and consistently while leaving intact the existing successes.

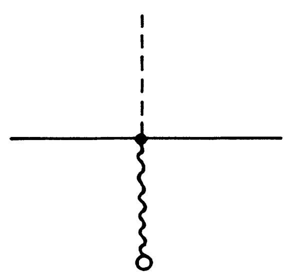

FIG. 5. The equivalence-breaking term, with nucleon, pion, and external scalar potential lines (full, dashed, and wavy, respectively).

In view of the large sensitivity in our results to the type of coupling (pseudoscalar or pseudovector) used at the KNY vertices, it is important to understand which one of the two types is more appropriate.[13] In fact, the preferred type of coupling in the lowest-order transition operator depends on the organization of the underlying strong-coupling relativistic field theory with pseudoscalar mesons. There may be large corrections to both types of couplings treated here. What is missing (and required) is a relativistic theory that tells us what the correction terms are (whether the theory is organized on the basis of a pseudoscalar or a pseudovector type coupling) to the lowest-order diagrams considered here. Stated somewhat differently,[13] what is needed is a careful investigation of the higher-order relativistic many-body corrections to our transition operator, and this is difficult at present in the absence of a satisfactory Lagrangian.

At present, the status of research concerning this problem concentrates on the πN system and is best characterized by two results.[14] First, existing self-consistent relativistic calculations of pion-nuclear dynamics may indicate a preference for the PV (over PS) coupling. It may be that a PV π-N Lagrangian is more economical than its PS counterpart, in the sense that it reduces the number of necessary corrections. The second of the two results deals with the question of chiral symmetry needed in order to reasonably account for low-energy pion dynamics. Such chiral models introduce strong nonlinearities in the scalar field, changing significantly the binding energy per nucleon in nuclear matter. Furthermore, nuclear-matter mean-field-theory solutions corresponding to abnormal nuclear matter (second minimum in the energy per nucleon) can now be obtained in addition to the conventional nuclear matter solution. The saturation of nuclear matter has not been successfully explained in a consistent chirally symmetric theory. What is needed is a Lagrangian theory that would correctly describe both the properties of nuclear matter and the low-energy optical potential for pions in the nuclear medium.

In view of this discussion it is clear that the relativistic calculation of the electromagnetic production of pions and kaons is subject to considerable uncertainties at present. In particular, it is not possible to claim any new features in the (γ,K^+) reaction based solely on a PS calculation.[11] Furthermore, the authors of Ref. 11 use free-particle propagators for the baryons in their calculation. As Figs. 3 and 4 demonstrate clearly, the many-body modifications of the propagators cannot be neglected.

We wish to comment now on another general problem encountered when using a relativistic nuclear structure model. Theories such as QHD suggest important corrections to the diagrams included in the present calculation. The presence of several-hundred-MeV-strong potentials, combined with a response of the vacuum to an external perturbation via the intermediate production of $N\bar{N}$ pairs in the nuclear environment, should motivate the study of additional terms involving vector meson exchanges. Several studies[20–23] have already reported results indicating that some large relativistic effects originating from the presence of the attractive scalar potential can be significantly decreased due to terms involving the space components of the four-vector field [Eqs. (5) and (7)]. This mechanism would effectively renormalize the kaon-photoproduction operator in the many-body medium. It has recently been shown that this kind of operator renormalization has interesting effects especially in hypernuclear systems.[24] The implications of this mechanism should be studied before any firm conclusion can be drawn from the relativistic calculations. It would be extremely interesting if this kind of many-body effect could resolve the question of the real meaning of large relativistic effects.

In summary, we have discussed some of the properties of the kaon photoproduction operator both for free particles and for a nuclear process. We have compared the PS and PV operators, showing their similarities and the source of differences between the two coupling schemes. The problem of the large kaon mass has been pointed out. For the nuclear process, we focused on the relativistic nuclear structure model, where large differences exist between PS and PV theories. In addition to demonstrating these differences, we have discussed the reasons for the discrepancies between the two theories, and pointed out the missing ingredients that are relevant to our study and need to be solved in the pertinent nuclear structure model.

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APPENDIX: EFFECTIVE-LAGRANGIAN APPROACH TO K^+-NUCLEON SCATTERING AND K^+-PHOTOPRODUCTION (REF. 25)

The various effective-Lagrangian (or tree-level Feynman diagrams) approaches are a popular tool in intermediate energy nuclear physics. Such phenomenological Lagrangians have been applied to a variety of medium-energy nuclear calculations.

In this appendix we calculate low-energy K^+-nucleon scattering parameters employing a commonly used effective Lagrangian, and confront the results with the experimental numbers. The motivation for this work comes from the large discrepancies between KNY coupling constants obtained through the reaction $\gamma p \rightarrow K^+\Lambda$ when analyzed using a model borrowed from (γ,π), and the canonical values of the same coupling constants.[1] Consequently, a relation to the (γ,K^+) reaction will also emerge in this appendix. We emphasize that we *do not* attempt here to build a Lagrangian for describing the elementary-particle reactions dealt with, but rather to test an existing model and shed light on existing disagreements in the literature.

The K^+N scattering is described by the usual Lorentz-invariant scattering (4×4 Dirac) T matrix. Tree-level expressions are obtained for the scattering parameters (i.e., scattering lengths and volumes and effective ranges). The Born term (u channel) using standard values of the coupling constants (see Ref. 1) yields results in very poor agreement with experiment. Adding a σ-exchange (t-channel) graph, we can reproduce the experimental value of the isospin-0 scattering length, but only by worsening the result obtaining for the corresponding isospin-1 quantity. Values of the σ mass, needed to account for other parameters, vary from one parameter to another, and are often rather too small for a particle that decays quickly into two kaons. *It is clear that the proposed effective Lagrangian with the canonical values for the coupling constants cannot be used for a reliable description of process involving K^+'s and nucleons.*

The same kind of phenomenological Lagrangian has also been adopted for the description of K^+ photoproduction,[2] providing another set of coupling constants. These differ appreciably from the standard values discussed so far. We have put these values to test in our present calculations of K^+N scattering. Given the crudeness of the photoproduction data, the values obtained for the scattering lengths are in much better agreement with experiment. With the Born term only, the effect on the rest of the scattering parameters is inconclusive. With the σ-exchange contribution added, we find that a universal agreement with experiment is ruled out. However, $a_{I=0}$ and $a_{I=1}$ are fairly well reproduced. Recalling that, in the π-N sector, the main success is the sum-rule $2a_{3/2}+a_{1/2}\simeq 0$ (and the rest of the low-energy scattering parameters are essentially unexplained), we may conclude that the second set of coupling constants discussed here is more favorable. When this model is used, *the standard values of the coupling constants seem to be ruled out by the data.* If this conclusion is true, then π-N and K^+-N low-energy scattering are theoretically accounted for at a similar level of accuracy (using the other set of constants).

A few other possibilities should also be considered. It may well be that the effective Lagrangian based on the σ model is not a good starting point for the description of processes involving mesons and baryons. Or, the problem may lie in the large mass of the kaon, without affecting the π-N system. [Indeed, the Kroll-Ruderman theorem tells us that the (γ,K^+) reaction is not a good source of information for determining the required coupling constants.] A more speculative conclusion involves the contribution of Z^* five-quark resonances, contributing in the s-channel diagram. Some additional tests (and caution) are needed in the interpretation of these results.

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[19]As a further illustration, we assume infinite nuclear matter and plane waves. The baryon single-particle energies for momentum k are, then, $\epsilon_B(k)^{(\pm)}=\pm(k^2+M_B^{*2})+U_V^B$. In dealing with nucleons only, the vector potential U_V^B provides the reference level, and will not appear in any calculated physical measureable quantity. When both nucleons and a Λ are involved, the Λ-single-particle energies will be measured relative to U_V^N, and therefore depend on $U_V^N-U_V^N$. This picture is oversimplified, however, in the sense that the Λ polarized the nuclear matter; in a more satisfactory approach the response of the latter to the former should be calculated. Work along these lines will be described elsewhere.

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