PHYSICAL REVIEW VOLUME 107, NUMBER 2 JULY 15, 1957

Photoproduction of K Mesons from Single Nucleons*

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(Received April 15, 1957)

Perturbation calculations of the lowest order are carried out for K-meson photoproduction from single nucleons. Results are given for scalar and pseudoscalar mesons, with or without anomalous magnetic moments for the nucleons and hyperons, and with scalar, pseudoscalar, vector, and pseudovector couplings. Numerical results are given assuming unity for the coupling constant. The difference between the present results and those carried out for pion photoproduction is due to the mass difference of the nucleons and hyperons, the larger ratio of the meson mass to the nucleon mass, and the different values for the anomalous magnetic moments. The last of these effects is particularly striking and might be of practical significance when sufficient experimental information is available.

I. INTRODUCTION

THIS paper presents calculations in the lowest order perturbation approximation of the photoproduction of K mesons from single nucleons.[1] While the validity of such calculations in the case of the K meson-nucleon interaction depends, roughly speaking, on the magnitude of the K meson-nucleon coupling constant, an *a priori* skepticism concerning the success of such an approach is quite justified, especially in view of our experience with the pion-nucleon interaction.

It is reasonable, therefore, to begin our considerations by trying to present a *raison d'être* for perturbation calculations as applied to the K meson-nucleon interaction. We think that there is a case to be made even apart from pointing out the possibility that the interaction in question might be weak enough for the perturbation approximation to hold. The history of the pion-nucleon interaction shows that while the perturbation calculations gave very poor agreement with experimental data (especially so for the angular distributions), the qualitative features of the *discrepancy* between experiments and the perturbation results served as a stimulant for a phenomenological theory which in the end could be justified by more basic calculations. The perturbation calculations were the starting point, leading to the realization for instance in the case of pion photoproduction, that we can retain the perturbation predictions for the entire meson current contribution and for most of the nucleon current contribution and change only the $P\frac{3}{2}, \frac{3}{2}$ nucleon current contribution to get a good agreement with experiments. We suggest that perturbation calculations might also serve as a basis for the theory of K meson-nucleon interaction which will evolve, once sufficient guidance from experimental results is available.

* Assisted by the Air Force Office of Scientific Research and the U. S. Atomic Energy Commission.

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[1] Similar investigations have been carried out simultaneously but independently by A. Fujii and R. E. Marshak, following paper [Phys. Rev. **107**, 570 (1957)]. The two articles were coordinated prior to publication in order to avoid duplication.

II. GENERAL CONSIDERATIONS

The following notation will be used. M will denote the nucleon mass, and $\mathfrak{M}$ the hyperon mass. The K-meson mass will be denoted by μ. The units $\hbar=c=1$ will be used. The meaning of the other symbols is as follows: k for momentum (and energy) of the incoming photon, p for the momentum of the incoming nucleon, q for the momentum of the outgoing meson, p' for the momentum of the outgoing hyperon, ϵ for the polarization vector of the photon, q_0 for the total energy of the outgoing meson, and $E(p)$ and $E(p')$ for the total energy of the incoming nucleon and outgoing hyperon, respectively. Boldface letters stand for three-dimensional vectors, while italics denote four-dimensional vectors. Scalars are also denoted by italics, but this ambiguity causes no confusion with the possible exception of Eq. (2.7) where p^2 and p'^2 denote the squares of the four-vectors. Our γ's are defined so that γ_0 is Hermitian and its square is unity, while the other three γ_i's are anti-Hermitian and their square is -1. Our scalar product is defined by $a\cdot b=a_0b_0-\mathbf{a}\cdot\mathbf{b}$, and we use $\not{a}=a_0\gamma_0-\mathbf{a}\cdot\boldsymbol{\gamma}$.

Our calculations will be carried out in the center-of-mass system. We chose this system for its simplicity and because experimental data are also likely to be given in this system. The kinematics of the reactions is trivial and will not be discussed. The threshold for production of a K meson together with a Λ meson is at a photon laboratory energy of 910 Mev, and for the production of a K meson with a Σ meson is at 1040 Mev.

At the present time the spin and parity of the hyperons and the K meson are not known, and in fact it is still open to question whether the K meson is a parity doublet or not. As far as spin is concerned, our calculations have been based on the assumption that the spin of the K meson is 0, and the spin of the hyperon is $\frac{1}{2}$. This assumption appears to be the most probable both on general theoretical and on experimental grounds.

As far as parity is concerned, we have calculated for both scalar and pseudoscalar K mesons. If the K meson is a parity doublet, the actual cross section is some linear combination of the cross sections for the two definite parity states. Since parity is conserved in photoproduction, no cross terms between the two parity states of the K meson can enter. It should be mentioned that because of the associated production of hyperons and K mesons, only the relative parity between a hyperon and a K meson has meaning. If we use the convention of defining the parity of the hyperon to be the same as that of a nucleon, our parity nomenclature refers directly to the parity of the K meson.

Strangeness considerations prohibit K^- and $\bar{K}^0$ production and so there are only six possible reactions:

$$\begin{aligned} &(1) \quad \gamma+p\rightarrow K^0+\Sigma^+,\\ &(2a) \quad \gamma+p\rightarrow K^++\Sigma^0,\\ &(2b) \quad \gamma+p\rightarrow K^++\Lambda^0,\\ &(3a) \quad \gamma+n\rightarrow K^0+\Sigma^0,\\ &(3b) \quad \gamma+n\rightarrow K^0+\Lambda^0,\\ &(4) \quad \gamma+n\rightarrow K^++\Sigma^-. \end{aligned} \tag{2.1}$$

In isotopic spin notation the interaction between hyperons, nucleons, and K mesons can be written as

$$G_\Sigma\bar{\psi}_{\Sigma i}\tau_i\Gamma\psi_N\varphi_K \quad \text{and} \quad G_\Lambda\bar{\psi}_\Lambda\Gamma\psi_N\varphi_K, \tag{2.2}$$

where Γ is unity for scalar mesons and $\Gamma=\gamma_5\equiv\gamma_0\gamma_1\gamma_2\gamma_3$ for pseudoscalar mesons. If one does not use the isotopic notation, the interactions involving *charged* Σ's are

$$\sqrt{2}G_\Sigma\bar{\psi}_\Sigma\Gamma\psi_N\varphi_K, \tag{2.3}$$

while those involving Σ^0 and Λ^0 remain uncharged. Our numerical results and graphs are given for the case when

$$G_\Sigma/(4\pi)^{\frac{1}{2}}=G_\Lambda/(4\pi)^{\frac{1}{2}}=1. \tag{2.4}$$

In our units $e^2/4\pi=1/137$.

The matrix element of a given process can be constructed from the contributions of the various graphs by using Feynman's method. Our numerical and normalization factors will be in agreement with a set of rules given by Schweber.[2] The matrix element so constructed will be denoted by T_{ab}. The differential cross section is then given by[2]

$$\frac{d\sigma}{d\Omega}=(2\pi)^2\frac{qq_0\mathfrak{C}}{[1+q_0/E(p')][1+k/E(p)]}, \tag{2.5}$$

where

$$\mathfrak{C}=|T_{ba}|^2/\delta^{(4)}(0)\delta^{(4)}(k+p-q-p'). \tag{2.6}$$

We have outlined the above procedure on account of the frequent confusion about the status of factors like $\sqrt{2}$ and 4π.

Finally, before we give the results of the calculations, let us see in what respect we can expect the results to be different from similar calculations carried out for pion photoproduction.[3]

[2] Schweber, Bethe, and de Hoffmann, *Mesons and Fields* (Row Peterson and Company, Evanston, 1955), Vol. I, pp. 242, 247, 248–254.

[3] G. Araki, Progr. Theoret. Phys. Japan 5, 507 (1950).

There are three types of differences. One is due to the fact that final state contains a hyperon instead of the initial nucleon, and in one of the graphs even the intermediate state is a hyperon. This fact brings about certain additional terms, not present in pion photoproduction, which will be proportional to some power of the difference between the mass of the nucleon and the hyperon. Secondly, the ratio of the meson mass to the nucleon mass is not 1/7 as it was in the case of the pion, but $\frac{1}{2}$, which makes the so-called "recoil terms" more important. Finally, when we include the effects of the anomalous magnetic moments, the values of the moments of the hyperons enters our formulas.

An example of an effect of the first type is the modified form of the equivalence theorem between the pseudoscalar (PS) and pseudovector (PV) couplings. Fortunately the modification is just in the numerical factor. The theorem can now be formulated as follows.

Let us consider a K meson being emitted by a nucleon. The initial or final baryon need not be a free particle. The part of the matrix element describing this process is, for PS coupling,

$$\begin{aligned} &\frac{p'+\mathfrak{M}}{p'^2-\mathfrak{M}^2}\gamma_5\frac{p+M}{p^2-M^2}\\ &=\frac{1}{\mathfrak{M}+M}\frac{p'+\mathfrak{M}}{p'^2-\mathfrak{M}^2}\\ &\qquad\times\gamma_5[p'+\mathfrak{M}-p+M-(p'-p)]\frac{p+M}{p^2-M^2}\\ &=\frac{1}{\mathfrak{M}+M}\left\{-\gamma_5\frac{p+M}{p^2-M^2}-\frac{p'+\mathfrak{M}}{p'^2-\mathfrak{M}^2}\gamma_5\right.\\ &\qquad\left.-\frac{p'+\mathfrak{M}}{p'^2-\mathfrak{M}^2}\gamma_5 q\frac{p+M}{p^2-M^2}\right\}. \end{aligned} \tag{2.7}$$

In the first-order photoproduction process the first two terms disappear for the meson-current graph, thus proving complete equivalence between the two couplings for this graph. For either of the two nucleon-current graphs, only one of the first two terms disappears. The other, however, gives the "catastrophic interaction" term. Thus for the lowest order calculations without anomalous magnetic moments over-all equivalence still holds. This, and a similar argument for the scalar meson, can be summarized in the following equivalence relation:

$$G\Gamma\rightarrow\frac{G}{M\mp\mathfrak{M}}\Gamma q, \tag{2.8}$$

where $+$ holds for the pseudoscalar meson and $-$ for the scalar meson.

In this paper, therefore, we shall use scalar and pseudoscalar couplings unless indicated otherwise.

III. CALCULATIONS

We shall carry out only one of the calculations in any detail, and shall state only the results of the other cases we have considered. It is assumed that the spin of the K meson is 0 and the spin of the hyperons is $\frac{1}{2}$.

1. Positive-K-Meson Production from Proton with Dirac Magnetic Moment

The graphs for the lowest order processes are indicated in Fig. 1. The double solid lines indicate hyperons, the solid lines nucleons, the broken lines K mesons, and the wavy lines photons. For the case under consideration, only graphs (a) and (b) contribute, since the Λ^0 (or Σ^0), having no charge or Dirac moment, does not interact with the photon. The contribution from these two graphs gives

$$T_{ba}=-\frac{i}{(2\pi)^2}\frac{eG(M\mathfrak{M})^{\frac{1}{2}}}{[2k2q_0E(p)E(p')]^{\frac{1}{2}}}w(p')\Gamma \times\left(\frac{q\cdot\epsilon}{q\cdot k}-\frac{\boldsymbol{k}\boldsymbol{\varepsilon}}{2p\cdot k}\right)u(p)\delta^{(4)}(p-q+k-p'), \quad (3.1)$$

where the integration over the intermediate meson four-vector has already been carried out. In deriving Eq. (3.1) we used $p\cdot\epsilon=0$ which holds both in the center-of-mass system and in the laboratory system.

We can easily convince ourself that Casimir's rule still holds even though we have different spinors in the initial and final states. Thus we have

$$|T_{ba}|^2=(2\pi)^{-4}\frac{e^2G^2M\mathfrak{M}}{8kq_0E(p)E(p')} \times\mathrm{Tr}\left\{\left(\frac{q\cdot\epsilon}{q\cdot k}-\frac{\boldsymbol{k}\boldsymbol{\varepsilon}}{2p\cdot k}\right)\Gamma\frac{p+M}{2M}\Gamma\left(\frac{q\cdot\epsilon}{q\cdot k}-\frac{\boldsymbol{\varepsilon}\boldsymbol{k}}{2p\cdot k}\right)\frac{p'+\mathfrak{M}}{2\mathfrak{M}}\right\} \times\delta^{(4)}(0)\delta^{(4)}(p-q+k-p'). \quad (3.2)$$

The computation of the trace yields

$$|T_{ba}|^2=\frac{e^2G^2}{(2\pi)^4 4kq_0E(p)E(p')} \times\delta^{(4)}(0)\delta^{(4)}(p-q+k-p')K_0, \quad (3.3)$$

where K_0 is, for scalar mesons,

$$K_{0S}=\left(2M\mathfrak{M}-\frac{\mu^2-(\mathfrak{M}-M)^2}{2}\right) \times\frac{q^2}{k^2}\frac{\sin^2\theta}{(q_0-q\cos\theta)^2}+1-\frac{q_0-q\cos\theta}{E(p)+k}, \quad (3.4)$$

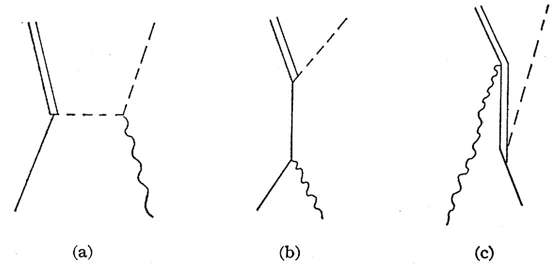

FIG. 1. Graphs for the lowest order K-meson photoproduction process. Solid lines represent nucleons, double lines hyperons, dashed lines mesons, and wavy lines photons.

and, for pseudoscalar mesons,

$$K_{0PS}=-\left(\frac{\mu^2-(\mathfrak{M}-M)^2}{2}\right)\frac{q^2}{k^2}\frac{\sin^2\theta}{(q_0-q\cos\theta)^2}+1 -\frac{q_0-q\cos\theta}{E(p)+k}, \quad (3.5)$$

where θ is the angle the emitted meson makes with the incoming photon in the center-of-mass system. The corresponding cross sections can be obtained by using Eq. (2.5). The result is, in the center-of-mass system,

$$\left(\frac{d\sigma}{d\Omega}\right)_2=\frac{1}{4}\frac{e^2G^2}{(4\pi)^2}\frac{q}{k}\frac{1}{[E(p)+k][E(p')+q_0]}K_0. \quad (3.6)$$

To obtain the total cross section, the integration over θ can be carried out easily. The result is

$$\sigma_2=2\pi\frac{e^2G^2}{(4\pi)^2}\frac{q}{k^3}[E(p)+k]^{-1}[E(p')+q_0]^{-1} \times\left\{k^2\left(1-\frac{q_0}{E(p)+k}\right)-[4\mathfrak{M}M\lambda-(\mu^2-(\mathfrak{M}-M)^2)] \times\left[1-\frac{q_0}{2q}\ln\left|\frac{q_0+q}{q_0-q}\right|\right]\right\}, \quad (3.7)$$

where

$$\lambda=+1 \text{ for scalar meson}$$
$$=0 \text{ for pseudoscalar meson.} \quad (3.8)$$

The angular distribution and the excitation function for the above-considered process is given in Figs. 2, 3, and 4.

2. Other K-Meson Production Processes from Single Nucleons with Dirac Magnetic Moments

The remaining four reactions of Eq. (2.1) can be calculated similarly. Reaction 1 will get contributions from graphs (b) and (c), and reaction 4 from graphs (a) and (c). Reaction 3 has no contributions from any of these graphs, and thus has zero cross section according to the theory under consideration.

The differential cross sections for reactions 1 and 4

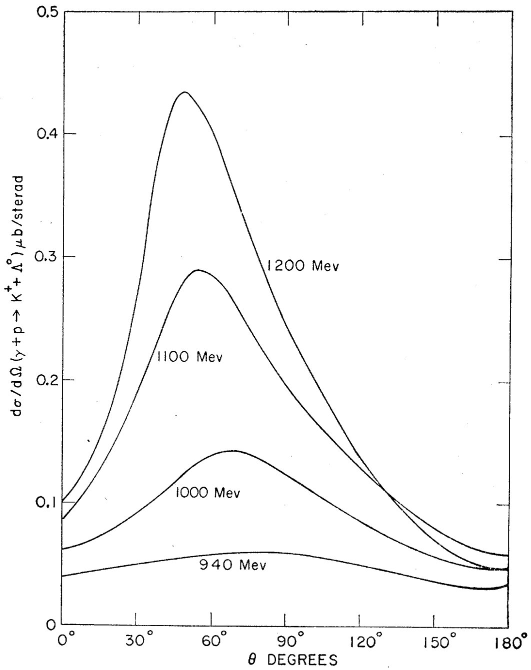

FIG. 2. Differential cross section in the center-of-mass system for reaction 2(b) with scalar coupling without anomalous magnetic moments.

are given by

$$\left(\frac{d\sigma}{d\Omega}\right)_1=2\left(\frac{d\sigma}{d\Omega}\right)_2\left(\frac{q_0-q\cos\theta}{E(p')+q\cos\theta}\right)^2, \tag{3.9}$$

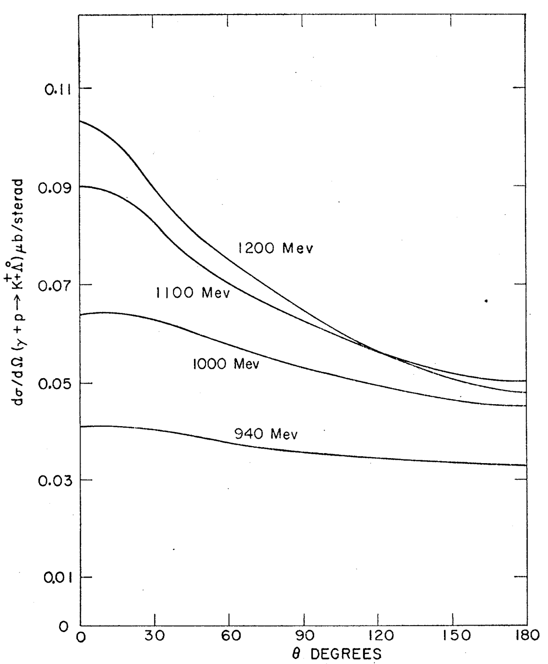

FIG. 3. Differential cross section in the center-of-mass system for reaction 2(b) with pseudoscalar coupling without anomalous magnetic moments.

and

$$\left(\frac{d\sigma}{d\Omega}\right)_4=2\left(\frac{d\sigma}{d\Omega}\right)_2\left(\frac{E(p)+k}{E(p')+q\cos\theta}\right)^2, \tag{3.10}$$

while the corresponding total cross sections are

$$\sigma_1=4\pi B\left\{\left[(E(p)+k)+2A\frac{E(p')}{k^2}\right]\frac{1}{q}\ln\left|\frac{E(p')+q}{E(p')-q}\right| -2\frac{E(p')+2q_0}{E(p)+k}-4\frac{A}{k^2}\right\}, \tag{3.11}$$

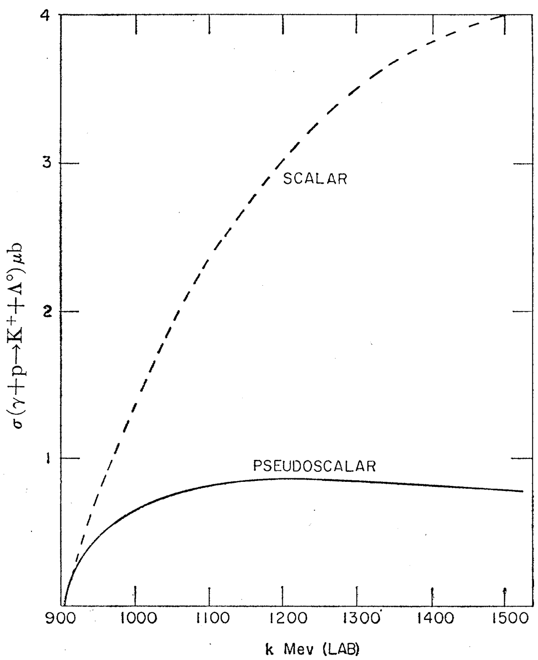

FIG. 4. Total cross section for reaction 2(b) with scalar and pseudoscalar couplings without anomalous magnetic moments.

and

$$\sigma_4=8\pi B\left\{-\frac{2A}{k^2}+\frac{A}{qk^2}\frac{q_0E(p')+q^2}{E(p')+q_0}\ln\left|\frac{q_0+q}{q_0-q}\right| +\left(\frac{A}{qk^2}\frac{q_0E(p')+q^2}{E(p')+q_0}+\frac{E(p)+k}{2q}\right)\ln\left|\frac{E(p')+q}{E(p')-q}\right|\right\}, \tag{3.12}$$

where

$$A\equiv-\tfrac{1}{2}[\mu^2-(\mathfrak{M}\pm M)^2], \tag{3.13}$$

and

$$B\equiv\frac{1}{4}\frac{e^2G^2}{(4\pi)^2}\frac{q}{k}\frac{1}{[E(p)+k]^2}. \tag{3.14}$$

Here, as well as in the subsequent formulas, the upper sign holds for the scalar case and the lower sign for the pseudoscalar case.

The differential cross sections and the excitation functions as predicted by the above formulas are given in Figs. 5 and 6.

3. Productions Involving Baryons with Anomalous Magnetic Moment

The anomalous magnetic moment calculations were carried out in a way similar to Kaplon's[4] calculation for pion photoproduction. The matrix element of a given process with the inclusion of the anomalous-magnetic-moment interaction can be thought of as the sum of two contributions, one being the matrix element obtained without considering the anomalous moments, and the other the added effect of the moments. This latter addition to the matrix element is, apart from the numerical value of the moments, the same for all four reactions. The cross section can therefore be written as

$$\left(\frac{d\sigma}{d\Omega}\right)_i=\eta_i B[Q_i^2K_0+Q_iK_1+K_2], \tag{3.15}$$

where K_0 is the expression given by Eq. (3.7), K_1 is given by

$$K_1=\left(\mu_N\mp\mu_Y\frac{M}{\mathfrak{M}}\right)\left(\pm\frac{\mathfrak{M}}{M}+1-\frac{q_0-q\cos\theta}{E(p)+k}\right), \tag{3.16}$$

and K_2 is given by

$$\begin{aligned}K_2=&\frac{1}{2}\left[\left(\frac{\mu_N}{M}\right)^2+\left(\frac{\mu_Y}{\mathfrak{M}}\right)^2\right][A+k(q_0-q\cos\theta)]\\ &\pm\frac{\mu_N\mu_Y}{M\mathfrak{M}}\left[-\frac{q^2}{2}\sin^2\theta\frac{E(p)+k}{E(p')+q\cos\theta}+A+k(q_0-q\cos\theta)\right.\\ &\left.-\frac{\{[E(p)+k]\mathfrak{M}\pm M[E(p')+q\cos\theta]\}^2}{[E(p')+k][E(p')+q\cos\theta]}\right],\end{aligned} \tag{3.17}$$

where μ_N is the nucleon anomalous magnetic moment in units of nucleon magneton, and μ_Y is the hyperon anomalous moment in terms of hyperon magnetons.[5] Q_i is a multiplicative factor depending on the reaction one considers. It is given by[6]

$$\begin{aligned}Q_1&=-\frac{E(p)+k}{E(p')+q\cos\theta},\quad Q_2=1,\\ Q_3&=0,\qquad\qquad Q_4=-\frac{q_0-q\cos\theta}{E(p')+q\cos\theta}.\end{aligned} \tag{3.18}$$

[4] M. F. Kaplon, Phys. Rev. **83**, 712 (1951).

[5] In the limit when the hyperon and nucleon masses are taken to be equal our expressions agree with those given by Kaplon, except for K_1 in the scalar case, where we believe there is an error in Kaplon's formula.

[6] The result for reaction 3 is the most uncertain since all of the cross section arises from the anomalous-magnetic-moment interaction, and since the possibility of the Λ^0 changing into a Σ^0 after the absorption of the photon, or *vice versa*, has not been considered. Nevertheless we include this result for the sake of completeness.

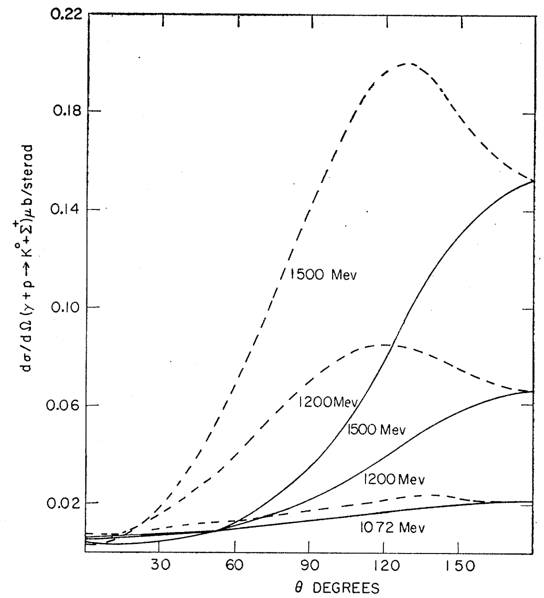

FIG. 5. Differential cross section in the center-of-mass system for reaction 1 excluding anomalous magnetic moments. The scalar theory is shown by the dashed line and the pseudoscalar theory by the solid line.

Finally η_i is 2 for reactions 1 and 4, and unity for the other processes. Some of the differential cross sections for the processes including anomalous moments are given in Figs. 7–10.

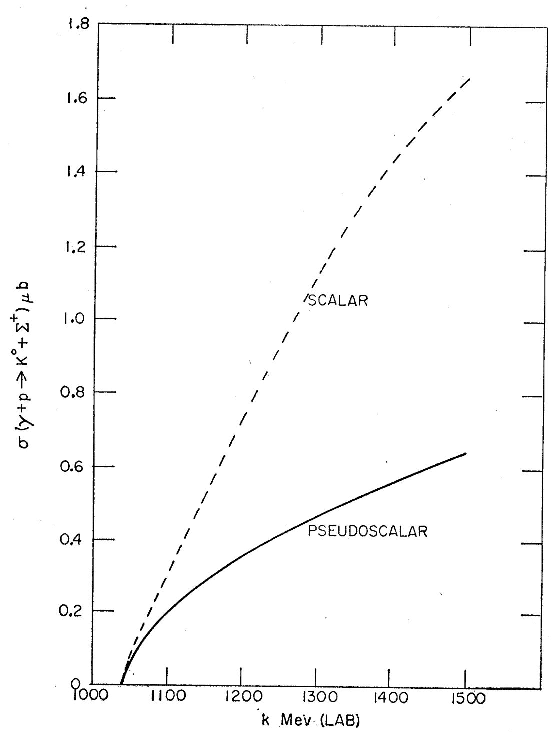

FIG. 6. Total cross section for reaction 1 with scalar and pseudoscaler couplings without anomalous magnetic moments.

As is well known, the equivalence theorem ceases to be valid even in the lowest order when anomalous moments are included. The results of calculations carried out with vector and pseudovector couplings consist of the complete formula obtained by scalar and pseudoscalar couplings, plus an additional term which has one part which is linear in the anomalous moments, and one which is quadratic. This additional term is

$$2\left(\frac{\mu_N}{M}\mp\frac{\mu_Y}{\mathfrak{M}}\right)(\mathfrak{M}\mp M)Q_i \times\left\{-k[E(p')+q\cos\theta]\pm\frac{q^2}{2}[E(p)+k]\frac{\sin^2\theta}{(q_0-q\cos\theta)}\right\} +\left(\frac{\mu_N}{M}\mp\frac{\mu_Y}{\mathfrak{M}}\right)^2\{k^2[E(p)+k][E(p')+q\cos\theta] +(\mathfrak{M}\mp M)\{(\mathfrak{M}\pm M)k[E(p)+k] \mp Mk(q_0-q\cos\theta)\}\}. \quad (3.19)$$

In the absence of any experimental information on the hyperon moments, we referred to a theoretical estimate of Marshak, Okubo, and Suderarshan.[7] In the numerical computations we used the following values for the anomalous magnetic moments:

$$\mu(\Sigma^+)=1.33, \quad \mu(\Lambda^0)=-1.44, \quad (3.20)$$

in units of hyperon magnetons.

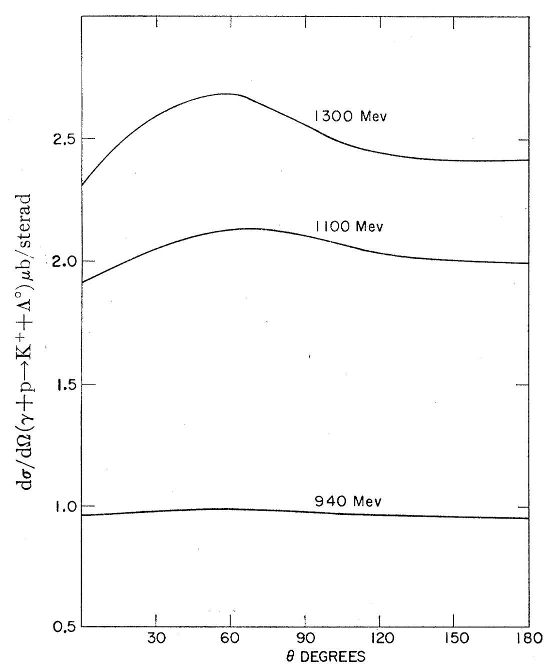

FIG. 7. Differential cross section in the center-of-mass system for reaction 2(b) with scalar coupling, including the effect of anomalous magnetic moments.

[7] Marshak, Okubo, and Sudarshan, Phys. Rev. **106**, 599 (1957).

In addition to the extra term given by Eq. (3.19) for the vector and pseudovector couplings the coupling constant must also be changed in accordance with Eq. (2.8). Therefore, in order to present an appropriate comparison of the various couplings, one should use for the vector and pseudovector coupling constants the numerical values of

$$G^2/4\pi=1/(M\mp\mathfrak{M})^2. \quad (3.21)$$

IV. CONCLUSIONS

Let us summarize our results by comparing them with the corresponding formulas for pion photoproduction.

The mass difference between the nucleon and the hyperon changes the results by an amount which depends on the form of the theory. In general, the correction is larger for the scalar theory than for the pseudoscalar case. In Fig. 2, for instance, the effect of the mass difference accounts for about 20% of the cross section. The effect is small compared to those obtained from perturbation calculations of K-meson *scattering* from nucleons (where the intermediate state contains a hyperon). In this latter process the mass difference can enter in denominators in a sensitive way, making the correction as large as a factor of 2 or larger.

In making a comparison between K-meson and pion photoproductions, one should take into account the difference in the isotopic spin structure. Thus, for instance, reaction 4 of Eq. (2.1) corresponds to negative-pion production from neutrons.

It is interesting to notice the maximum in the excitation curve for the pseudoscalar case in Fig. 4, brought about by the combined effect of the mass difference and large "recoil" terms. In general, one of

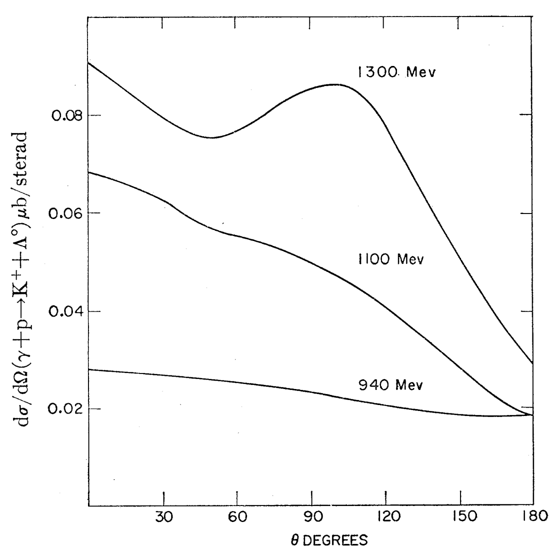

FIG. 8. Differential cross section in the center-of-mass system for reaction 2(b) with pseudoscalar coupling, including the effect of anomalous magnetic moments.

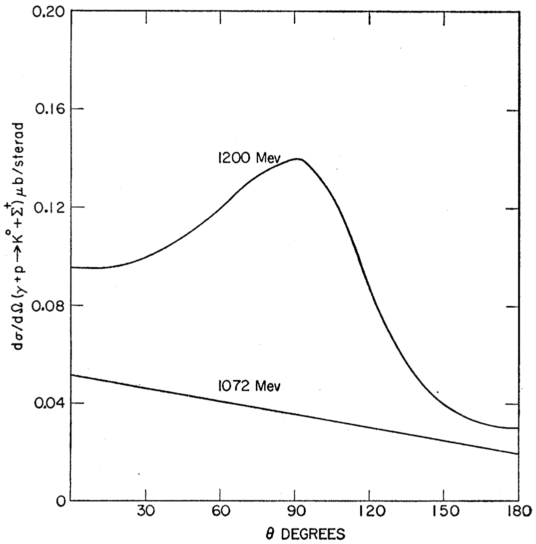

FIG. 9. Differential cross section in the center-of-mass system for reaction 1 with scalar coupling, including the effect of anomalous magnetic moments.

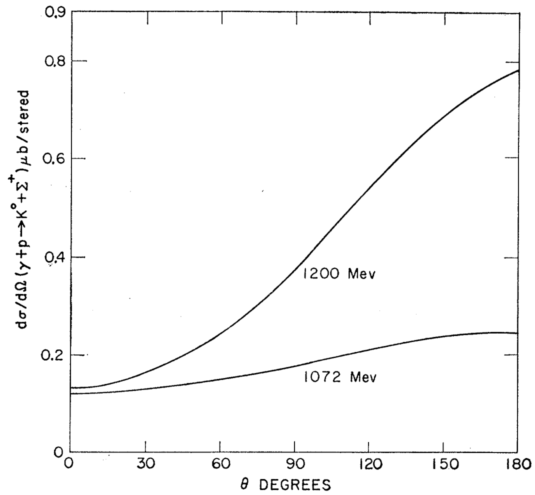

FIG. 10. Differential cross section in the center-of-mass system for reaction 1 with pseudoscalar coupling, including the effect of anomalous magnetic moments.

the most striking differences between the *K*-meson and pion photoproductions is the order of magnitude equality of neutral and charged productions. This is a direct consequence of the "recoil effects."

The effect of the addition of anomalous magnetic moments depends, of course, greatly on the numerical values of the anomalous moments. With the values chosen by us, there is relatively little change for reaction 1, and for the pseudoscalar coupling of reaction 2(b). However, the scalar case for reaction 2(b) changes by a large factor and the shape of the angular distribution is also altered drastically. The sensitivity of the excitation function to the addition of anomalous magnetic moments is discussed by Fujii and Marshak.[1]

It is also found that there is a large difference between the pseudoscalar and pseudovector, and scalar and vector couplings. In particular, the vector coupling gives a very large cross section.

In summary, we believe that the above results might be of use in several ways. The various possibilities differ from each other sufficiently, both in the magnitude of the cross section as well as in the shape of the angular distribution, to be of help in making a choice among them on the basis of a comparison with even quite rough experimental data. Coincidentally with this choice one might also be able to say something about the order of magnitude of the anomalous moments. Finally, once more precise data are available, the deviations from the above results, if they exist, might indicate the direction in which a more phenomenological theory should develop.

V. ACKNOWLEDGMENTS

One of the authors (M. J. M.) would like to thank Purdue University for the hospitality extended to him while part of the work was carried out. Part of the numerical calculations was carried out by Miss Regina Buckley, whose help is appreciated.