exhibit the scaling behavior (1) found in purely hadronic reactions at higher energies. It is found that when the cross section is expressed in terms of the missing mass, at a fixed missing mass and fixed center-of-mass angle, the W dependence is independent of the missing mass and is the same as the one found for pion production. This behavior agrees with the predictions of the constituent interchange model indicating that the cross section is dominated by elementary quark interactions of the form of Eqs. (12)–(14). The failure to observe scaling in the form predicted by Eq. (1) may be due to the fact that no single one of the elementary quark interactions dominates in this energy region.

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*Present address: Clinton P. Anderson Laboratory, Los Alamos, N. Mex. 87544.

[1]D. Sivers, S. J. Brodsky, and R. Blankenbecler, Phys. Rep. 23C, 1 (1976).

[2]F. W. Busser *et al.*, Phys. Lett. 46B, 471 (1973).

[3]J. W. Cronin *et al.*, Phys. Rev. D 11, 3105 (1976).

[4]R. Blankenbecler, S. J. Brodsky, and J. Gunion, Phys. Rev. D 12, 3469 (1975).

[5]W. B. Atwood, private communication.

[6]A. Browman *et al.*, Phys. Rev. Lett. 35, 1313 (1975).

[7]M. Herzlinger, Ph.D. thesis, Harvard University, 1975 (unpublished).

[8]J. C. Alder *et al.*, Nucl. Phys. B46, 415 (1972).

[9]H. Burfeindt *et al.*, Phys. Lett. 43B, 345 (1973).

[10]A. Browman *et al.*, Phys. Rev. Lett. 37, 651 (1976).

[11]R. Blankenbecler, S. J. Brodsky, and J. F. Gunion, Phys. Lett. 42B, 461 (1972), and Phys. Rev. D 6, 2652 (1972).

[12]P. Landshoff and S. C. Polkinghorne, Phys. Lett. 45B, 361 (1973).

[13]R. Blankenbecler and S. J. Brodsky, Phys. Rev. D 10, 2973 (1975).

Unitary Coupled-Channel Deck Model and the Q Meson Resonance Region

J. L. Basdevant*
Fermi National Accelerator Laboratory,† Batavia, Illinois 60510

and

E. L. Berger
High Energy Physics Division,‡ Argonne National Laboratory, Argonne, Illinois 60439

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We construct a unitary Deck model with coupled $K^*\pi$ and $K\rho$ channels, including only one resonance in the Q region. Adjusting the resonance parameters, we achieve a satisfactory description of the experimental phase variations and the structure in the mass spectra. The resonance is determined to belong to the $J^{PC}=1^{+-}$ SU(3) octet, and is thus the Q_B. The relative coupling strength $K^*\pi/K\rho$ is $\sim\frac{2}{3}$.

Among the two octets of axial-vector meson resonances predicted by the quark model, only the B meson has been unambiguously identified. The apparent absence of the others is an outstanding difficulty.[1] Very recently, a Stanford Linear Accelerator Center group[2] reported evidence for the existence of two strange axial-vector mesons, Q_1 and Q_2. Their conclusion is based both on structure in the $K^*\pi$ and $K\rho$ mass distributions and on observed phase variations. In this Letter, we show that all these significant features of the data may be understood in terms of only *one* axial-vector resonance and nonresonant Deck background.[3] The resonance couples to both the $K\rho$ and $K^*\pi$ channels. For reasons we describe, it must have odd charge-conjugation relative to the K. It is thus the Q_B, with $J^{PC}=1^{+-}$. We find that its mass lies between 1.3 and 1.4 GeV, and its width is of order 150 MeV. Our description of the data without a Q_A ($J^{PC}=1^{++}$) resonance is consistent with the apparent absence of a resonance signal in the $J^P=1^+\pi\rho$ A_1 system.[4]

We begin with two assumptions. First, there are nonresonant Deck amplitudes, sketched in Fig. 1, for both the $K^*\pi$ and $K\rho$ channels. Second, we assume that there is one $J^P=1^+$ reso-

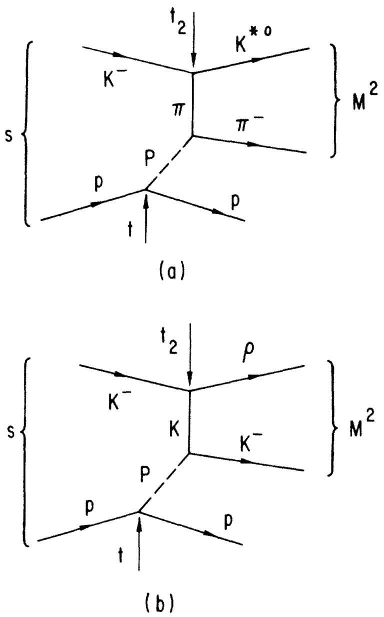

FIG. 1. (a) Pion-exchange Deck graph for $K^-p \to K^{*0}\pi^-p$; (b) kaon-exchange Deck graph for K^-p ρK^-p. The kinematic variables are indicated; P stands for the Pomeron exchange.

nance, with mass, width, and branching ratios to be determined, which couples to both the $K^*\pi$ and $K\rho$ channels. The rest is a classical two-channel problem of finding a properly analytic and unitary $J^P=1^+$ partial-wave amplitude which satisifes our assumptions. We then vary the parameters of the resonance to achieve an acceptable representation of the data. The structure in the data requires that the resonance have odd C.

The Deck model has been described at length elsewhere.[3] We quote here the analytic form valid near $t=0$ for the $J^P=1^+$ S-wave $K^*\pi$ amplitude, with helicity zero in the Gottfried-Jackson frame:

$$A_{K^*\pi}(s,M^2,t) = \frac{2g_{K^*K^+\pi^-}|\vec{K}_{K^*}|s\sigma_{\pi p}}{(M^2-m_K^{\,2})}\exp(b_\pi t). \qquad (1)$$

Kinematic variables are defined in Fig. 1. Here, $|\vec{K}_{K^*}|$ is the incident kaon three-momentum as seen in the K^* rest frame; $\sigma_{\pi p}$ is the asymptotic πp total cross section; b_π is the slope parameter for πp elastic scattering; and $g_{K^*K^+\pi^-}{}^2=4\pi(1.66)$.

Likewise, for the kaon-exchange Deck graph in Fig. 1(b), the $J^P=1^+$ S-wave helicity-zero $K\rho$ amplitude is

$$A_{\rho K}(s,M^2,t) = \frac{2g_{\rho KK}|\vec{K}_\rho|s\sigma_{Kp}}{(M^2-m_K^{\,2})}\exp(b_K t). \qquad (2)$$

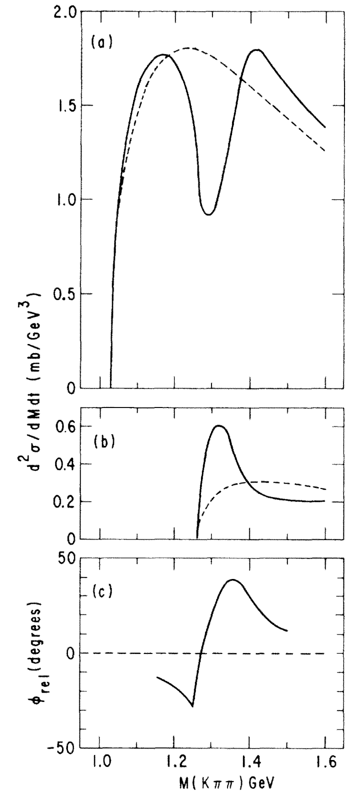

FIG. 2. Mass dependence at $t=0$ of $d^2\sigma/dMdt$ in the $J^P\lambda_t=1^+0$ partial wave for (a) the $K^*\pi$ and (b) the $K\rho$ channels. The dashed lines represent the pure Deck model. The solid lines are from our unitarized Deck model. We determine the mass and width of the Q_B resonance (1.34 and 0.15 GeV) from the position of the second sheet pole. These correspond to $\sqrt{s_1}=1.43$ GeV, $g=-0.35$, and $f=0.55$ in Eq. (4). (c) The phase of the 1^+ $K\rho$ amplitude measured with respect to the 1^+ $K^*\pi$ amplitude.

For normalization, we adopt the SU(3) relationship $2g_{\rho^0K^+K^-}=g_{\rho^0\pi^+\pi^-}$, with $g_{\rho^0\pi^+\pi^-}{}^2=4\pi(2.4)$. We evaluate $|\vec{K}_{K^*}|$ and $|\vec{K}_\rho|$ at $t_2^{\rm eff}=-0.2$ GeV^2 which we take to be independent of t and M. For the remaining part of this Letter, we specialize to $t=0$. In a more detailed paper in the future, we expect to address the variation with t as well as the full-spin problem.

We write the Deck contribution as a two-component vector:

$$T_D=\begin{pmatrix} A_{K^*\pi} \\ A_{\rho K}\end{pmatrix}. \qquad (3)$$

The Deck amplitudes provide featureless threshold enhancements shown as dashed lines in Fig. 2.

Our second assumption is that there is one resonance in the $J^P = 1^+$ S wave, which decays into both the $K^*\pi$ and $K\rho$. A unitary S matrix representing this coupled-channel scattering is easily constructed. We begin with the real symmetric K matrix

$$K = \begin{pmatrix} \frac{g^2}{s_1 - M^2} & \frac{gf}{s_1 - M^2} \\ \frac{gf}{s_1 - M^2} & \frac{f^2}{s_1 - M^2} \end{pmatrix}. \tag{4}$$

Here s_1 is related to the square of the mass of the resonance, and g and f, to its coupling constants to $K^*\pi$ and $K\rho$, respectively; $\alpha^2 = g^2 + f^2$. The S matrix is then

$$S = [1 - K(M^2)C^+(M^2)]^{-1}[1 - K(M^2)C^-(M^2)], \tag{5}$$

where the C matrix is diagonal, $(C)_{ij} = \delta_{ij}C_i(M^2)$. The C_1 and C_2 are the usual unequal-mass Chew-Mandelstam functions[5] for $K^*\pi$ and $K\rho$, respectively. E.g., $C_1(M^2)$ is cut from $M^2 = (m_{K^*} + m_\pi)^2$ to ∞; for $M \geq (m_{K^*} + m_\pi)$, it satisfies

$$\operatorname{Im}C_1(M^2) = 2q/M \equiv [M^2 - (m_{K^*} + m_\pi)^2]^{1/2}[M^2 - (m_{K^*} - m_\pi)^2]^{1/2}/M^2. \tag{6}$$

Each C_i is defined so that $C_i(0) = 0$. Equation (5) then provides a strong-interaction S matrix with proper analyticity and unitarity properties. For a given function $F(M^2)$, the notation $F^\pm(M^2)$ is used to denote $F(M^2 \pm i\epsilon)$, and $\Delta F(M^2) = (F^+ - F^-)/2i$.

We now face the standard problem of correcting a production mechanism, here the Deck amplitude, by final-state interactions.[6,7] In our case, we must use a coupled-channel formulation.[8] The $J^P = 1^+$ S-wave amplitude vector should be analytic in the complex M^2 plane cut from $-\infty$ to M_L^2 (left-hand cut) and from M_R^2 to $+\infty$ (right-hand cut). It should satisfy the following discontinuity relationships across these cuts: (a) $T^+(M^2) = S(M^2)T^-(M^2)$, $M^2 \geq M_R^2$; generalized Watson theorem,[9] where in the unitarity relation, we retain only the $K^*\pi$ and the $K\rho$ intermediate states. (b) The left-hand cut discontinuity is given by the Deck amplitude: $\Delta T(M^2) = \Delta T_D(M^2)$, for $M^2 \leq M_L^2$. Furthermore, we require that $T(M^2)$ reduce to $T_D(M^2)$ when the S matrix [Eq. (5)] is identically unity.[10]

The solution to this problem is the Cauchy integral[6-8]

$$T(M^2) = \frac{D(M^2)}{\pi}\int_{-\infty}^{M_L^2} \frac{D^{-1}(s')\Delta T_D(s')ds'}{(s' - s)}, \tag{7}$$

where $D(M^2)$ is an invertible 2×2 matrix, whose elements are analytic in M^2. $D(M^2)$ possesses only the right-hand cut and satisfies $D^+(M^2) = S(M^2)D^-(M^2)$ across this cut, above the thresholds.[11] $D(M^2)$ is unique up to normalization[8] which cancels in Eq. (7). The factorized form chosen for $K(M^2)$ in Eq. (4) permits us to obtain an analytic expression[8] for $D(M^2)$:

$$D(M^2) = \frac{1}{s_1 - M^2 - f^2C_2 - g^2C_1}\begin{pmatrix} gs_1 & -f(s_1 - M^2 - \alpha^2C_2) \\ fs_1 & g(s_1 - M^2 - \alpha^2C_1) \end{pmatrix}. \tag{8}$$

For the final $J^P = 1^+$ partial-wave amplitude, we derive

$$T(M^2) = \frac{\alpha^{-2}}{(s_1 - M^2 - f^2C_2 - g^2C_1)}\begin{bmatrix} A_{K^*\pi}(M^2)\{g^2[s_1 - m_K^2 - \alpha^2C_1(m_K^2)] + f^2[s_1 - M^2 - \alpha^2C_2(M^2)]\} \\ + gfA_{K\rho}(M^2)\{M^2 - m_K^2 - \alpha^2C_2(m_K^2) + \alpha^2C_2(M^2)\} \\ \\ A_{K\rho}(M^2)\{f^2[s_1 - m_K^2 - \alpha^2C_2(m_K^2)] + g^2[s_1 - M^2 - \alpha^2C_1(M^2)]\} \\ + gfA_{K^*\pi}(M^2)\{M^2 - m_K^2 - \alpha^2C_1(m_K^2) + \alpha^2C_1(M^2)\} \end{bmatrix}. \tag{9}$$

The upper element of the vector $T(M^2)$ is the $K^*\pi$ channel amplitude, whereas the lower is the $K\rho$ amplitude. The structure of each amplitude in Eq. (9) is that of a resonance term $(s_1 - M^2 - f^2C_2 - g^2C_1) \simeq (s_1 - M^2 - i\Gamma M)$ convoluted with a sum of the $K^*\pi$ and $K\rho$ Deck amplitudes. Moreover, multiplying each of the Deck amplitudes $A_{K^*\pi}$ and $A_{K\rho}$ is a complex function of M^2, with zeros in the real part occurring at values of M^2 fixed by the resonance parameters. These zeros provide structure in the cross section $d\sigma/dM$.

With the normalizations of the Deck amplitudes fixed, we vary f/g and observe the resultant changes in the $K^*\pi$ and $K\rho$ amplitudes. In Fig. 2, we present results in which the two peaks in the $K^*\pi$ spectrum have equal heights. The overall agreement with data[2] is qualitatively excellent and is even quantitative for the $K\rho$ mass distribution [Fig. 2(b)], the $K\rho$ versus $K^*\pi$ relative phase [Fig. 2(c)], and the relative cross sections. The results shown are insensitive to reasonable modifications of the Deck amplitudes. For example, the use of form factors in the π and K exchange legs of Fig. 1 may change the relative normalization of the two Deck terms. By making compensating changes in our (f/g) ratio, we can maintain the essential features of Fig. 2.

Several points should be emphasized. To obtain a dip in the $K^*\pi$ mass distribution, it is necessary that (f/g) be negative relative to $(g_{K^*K\pi}/g_{\rho KK})$. Therefore, the resonance must have odd C relative to the kaon. It is thus the Q_B with $J^{PC} = 1^{+-}$. The relative heights of the two peaks in the $K^*\pi$ mass spectrum, the width of the threshold structure in the $K\rho$ mass distribution, and the $K^*\pi$ versus $K\rho$ phase variation are controlled by the magnitude of (f/g). In our solution, we find $(f/g) \simeq 1.5$, with the $K\rho$ coupling favored. The SU(3) prediction is $(f/g) = -1$ for the Q_B. The position of the dip in the $K^*\pi$ spectrum is influenced by our choice of resonance position. We use $M_{\rm res} = 1340$ MeV to obtain the results in Fig. 2. Lowering this value, we would displace the dip to a lower mass. It is the resonance which generates the sharp structure near the $K\rho$ threshold.

The variation of $\varphi_{\rm rel}$ shown in Fig. 2(c) is in excellent agreement with the data, increasing from $-30°$ at $M \simeq 1.26$ GeV to $+40°$ at $M \simeq 1.35$ GeV, and then falling again. The phase of our $K^*\pi$ amplitude varies very slowly in the region $M > 1.35$ GeV, with an average value of $-5°$. Because of the $K^*(1420)$ resonance, we expect the 2^+ $K^*\pi$ phase to vary relative to the 1^+ $K^*\pi$ phase as M is increased through 1420 MeV. However, the rise may be limited because the $K^*\pi$ branching fraction of the $K^*(1420)$ is only 30%. Two experimental groups[2] indeed observed a phase increase of roughly $+50°$ in the neighborhood of the 1420, consistent with our expectations.

Two discrepancies may be noted between our theoretical curves (Fig. 2) and the data. We obtain roughly $\frac{2}{3}$ of the measured absolute cross section. Second, our $K^*\pi$ mass distribution is somewhat too broad. It rises too quickly from threshold and falls off too slowly above 1.4 GeV. Narrowing of the mass distribution can be accomplished with form factors in t_2 and/or Reggeization of the π and K exchanges in the Deck amplitudes. Otherwise, the K matrix, Eq. (4), can be improved, for instance by adding a nonresonant background. The shortage of overall cross section opens the issue of whether there is room for a second Q resonance, a state with $J^{PC} = 1^{++}$. In a more complete Deck amplitude, one would include graphs with K^* and ρ exchanges, in addition to the π and K exchange graphs shown in Fig. 1. Data suggest that these vector exchanges contribute with cross sections roughly equal to the pseudoscalar terms,[3] thereby making up the cross-section shortage. We believe only a very broad Q_A could be tolerated in our framework. Finally, the data at large $|t|$, where the cross section is relatively small, show that the $K^*\pi$ and $K\rho$ systems are produced with t-channel and s-channel helicity conservation, respectively.[2] We have investigated the helicity properties of the vector-exchange Deck graphs and find that they quite naturally supply this difference.[12]

*Present address: Laboratoire de Physique Théorique et Hautes Energies, 4 Place Jussieu, 75230 Paris, France.

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[1]For reviews consult J. Rosner, in *Proceedings of the Seventeenth International Conference on High Energy Physics, London, England, 1974*, edited by J. R. Smith (Rutherford High Energy Laboratory, Didcot, Berkshire, England, 1975); G. Fox, in *Experimental Meson Spectroscopy—1972*, AIP Conference Proceedings No. 8, edited by Kwan-Wu Lai and A. H. Rosenfeld (American Institute of Physics, New York, 1972).

[2]G. W. Brandenburg *et al.*, Phys. Rev. Lett. 36, 703, 706 (1976); see also G. Otter *et al.*, Nucl. Phys. B106, 77 (1976).

[3]E. Berger, in *Proceedings of the Daresbury Conference on Analysis of Three-Particle Decays and Meson Resonance Production, 1975*, edited by J. B. Dainton and A. J. G. Hey (Daresbury Nuclear Physics Laboratory, Daresbury, Warrington, Lancashire, England, 1975).

[4]G. Ascoli *et al.*, Phys. Rev. D 7, 669 (1973).

[5]G. F. Chew and S. Mandelstam, Phys. Rev. 119, 467 (1960); B. W. Lee, Phys. Rev. 120, 325 (1960).

[6]R. Omnès, Nuovo Cimento 8, 316 (1958), and in *High Energy Physics*, edited by C. DeWitt and M. Jacob (Gordon and Breach, New York, 1965).

[7]J. D. Jackson, Nuovo Cimento 25, 1038 (1962).

[8]O. Babelon, J.-L. Basdevant, D. Caillerie, and G. Mennessier, University of Paris Report No. PAR-LPTHE 76/03, 1976 (to be published).

[9]K. N. Watson, Phys. Rev. 88, 1163 (1952).

[10]Another possiblity is to require in addition that

$T(M^2) \to T_D(M^2)$ as $M^2 \to \infty$. This is a manifestation of the polynomial ambiguity of Ref. 8. In the range of parameters necessary to represent the data ($f/g < 0$), this other possibility does not lead to any appreciable change in our results.

[11]R. Warnock, Nuovo Cimento 50, 894 (1967), and 52A, 637 (1967).

[12]E. L. Berger and J. T. Donohue, Argonne National Laboratory Report No. ANL-HEP-PR-7648 (unpublished).

Equality of Analyzing Power and Polarization in the Reaction $^3H(p, n)^3He$

T. R. Donoghue, Sr. M. A. Doyle,* H. W. Clark, L. J. Dries, and J. L. Regner
Department of Physics, The Ohio State University,† Columbus Ohio 43210

and

W. Tornow,‡ R. C. Byrd, P. W. Lisowski, and R. L. Walter
Department of Physics, Duke University, Durham, North Carolina 27701, and Triangle Universities Nuclear Laboratory,§ Durham, North Carolina 27706

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The quantities A_y and P^y were remeasured for $E_p < 4$ MeV in the reaction $^3H(p,n)^3He$. Although our A_y data confirm previous data, our P^y values are appreciably larger than earlier results and in fact agree well with those for A_y. Elimination of the previously reported A_y-P^y difference has important consequences. Charge-symmetry-breaking effects must be small or nonexistent in this reaction; and the previously required f-wave admixture to the lowest $J^\pi = 2^-$ state of ^4He is no longer necessary.

Concern over the inequalities of the analyzing power A_y for an incident polarized beam and the polarization P^y for an incident unpolarized beam for (p, n) reactions began in 1971 with the reaction $^3H(p, n)^3He$. Haight *et al.*[1] compared their A_y data to the then existing P^y data and observed that the two quantities were essentially the same above 4 MeV, but differed appreciably below this energy, by about 20% of the experimental magnitude. This difference was particularly surprising as charge-independent R-matrix calculations[1] showed differences of less than 1%. Since then, several pertinent Letters have appeared. First, Arnold *et al.*[2] showed that the differences in these quantities provided fairly unambiguous evidence for an f-wave admixture to the lowest 2^- state in ^4He. Conzett[3] followed by showing that an equality of A_y and P^y is expected in (p, n) reactions connecting mirror nuclei. More significantly, he recognized that differences in these quantities imply a breaking of exact charge symmetry by the Coulomb interaction and hence measures of these differences provide a mechanism for investigating charge-symmetry-breaking terms in the nuclear interaction. Because of the significance of these differences in the reaction $^3H(p, n)^3He$ and because of suspected problems in the earlier experiments, we remeasured both quantities and report our results and conclusions in this Letter.

The A_y measurements were carried out using The Ohio State University polarized-ion-source facility[4] which yields beams of 50 nA with about 60% polarization. The neutrons were produced in a 0.23 mg/cm^2 titanium-tritium target and were detected by a pair of symmetrically located NE213 scintillators. Recoil spectra, gated for neutrons using conventional n-γ discrimination electronics, were accumulated, stored on magnetic disk, and subjected to further off-line data reduction. The A_y data were obtained by alternately measuring spectra with the beam polarized and unpolarized for equal total charge. After each A_y measurement, the beam polarization was obtained by inserting a ^4He polarimeter in front of the neutron target. Further experimental details will be given by Doyle *et al.*[5]

The results of these A_y measurements at 45° in the center-of-mass frame (c.m.) for $E_p = 1.75$ to 3.9 MeV are shown in Fig. 1(a) along with the earlier data of Haight *et al.*[1] and with a curve to guide the eye. The agreement between the two sets of data is quite good over the entire energy range. Besides confirming the earlier data, this agreement indicates that concerns over beam depolarization effects in the tandem accelerator terminal[1] and differences in experimental techniques are of little consequence. An angular distribution of A_y measured at 2.48 MeV is shown in Fig. 2(a) along with a fit to the data. Our data are in excellent agreement with the earlier data of Brown and Rohrer[6] plotted in this figure. For completeness, the A_y angular distribution of