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Abstract

Recent measurements and partial-wave analyses of KN scattering below 3 GeV/c are reviewed. There is a large amount of new data on K^+n elastic and charge-exchange scattering, both cross sections and polarizations, which has not yet been analysed. Forward dispersion relations predict a striking forward dip in the $K^0p \to K^+n$ differential cross section, which present neutral kaon beam measurements below 1.5 GeV/c are unable either to confirm or deny. K^+p elastic polarization below 870 MeV/c has been accurately measured for the first time. A K^+p partial-wave analysis using these data claims a Z_1^* resonance in the P_{13} wave at 1800 MeV. Spin-rotation parameter measurements near the backward direction would be a good experimental test for the existence of this Z_1^*. A partial-wave analysis of $K^+p \to K^0\Delta^{++}$ has found no evidence for a Z_1^* strongly coupled to the $K\Delta$ channel.

This review deals with measurements and partial-wave analyses of KN scattering below about 3 GeV/c which have appeared within the last two years. Earlier results, through the summer of 1976, are reviewed in Refs. 1-3. A list of recent and current measurements is given in Table I, where one sees that the most extensive advances of the last two years have been in K^+n elastic and charge-exchange scattering. Measurements of the charge-exchange differential cross section have been made in the range 250-2700 MeV/c by five experiments, and two of these measured $K^0p \to K^+n$ using a neutral kaon beam, thereby avoiding deuterium corrections. K^+n elastic polarization is being measured in the range 700-1900 MeV/c by three experiments in various stages of completion, and two of these experiments also measure charge-exchange polarization in the range 860-1900 MeV/c. To appreciate the significance of these polarization measurements, one must realize that at the time of the last comprehensive I=0 and 1 partial-wave analysis of KN scattering[15] the only K^+n polarization data extant were 5 data-points with large errors for $K^+n \rightarrow K^0p$ at 600 MeV/c.[16]

The new K^+n data will undoubtedly have a significant impact on the question of the existence of a Z_0^*. The I=0 and 1 analyses of BGRT[17] and Martin[15] found suggestive structure in the P_{01} and D_{03} waves around 1700-2000 MeV, but without the speed maxima necessary for clear resonance signals. None of the data listed in Table I were available to these analyses, and almost none of these data have yet been used in a partial-wave analysis[18]. Some of the new data[6,7] have been compared with existing analyses, but with inconclusive results. There is a clear need in the near future for a new combined I=0 and 1 partial-wave analysis using all the new K^+n data, either in combination with I=1 partial waves from K^+p analyses in the style of BGRT[17], or in direct combination with K^+p data in the style of Martin[15].

Even in the absence of such an analysis, at least one interesting experimental question is already posed by the new data. This has to do with the size of the $K^0p \rightarrow K^+n$ forward cross section. The present situation is summarized in Fig. 1, taken from a paper of Martin[21]. The forward $K^0p \rightarrow K^+n$ amplitude is dominantly real and its uncertainty comes primarily from the I=0 part, since the I=1 part is well known from $K^{\pm}p$ Coulomb interference measurements and dispersion relations[13,15]. Dispersion relation predictions for the forward cross section imply a striking forward dip if one accepts the conventional picture of a weakly repulsive S_{01} wave near threshold. Armitage et al.[6] have fit their cross section data with third and fifth order Legendre expansions, and found extrapolated forward cross sections several times larger than the dispersion relation predictions. However, as shown by Martin in Fig. 1, it is possible to reconcile the Armitage et al. data with the dispersion relation predictions by fitting the two simultaneously with Legendre expansions of at most fifth order. The predicted dip is therefore neither confirmed nor denied by the data of Fig. 1, and an experiment to measure the $K^op \rightarrow K^+n$ cross section at very small angles below 1.5 GeV/c would be of great interest. The use of a neutral kaon beam would be necessary, because the single-scattering contribution to $K^+d \rightarrow K^opp$ vanishes at zero momentum transfer due to the symmetry of the deuteron wave function. Although a turnover has been observed in $K^+n \rightarrow K^op$ at momenta down to about 2 GeV/c (see Banerjee et al.[8] and references therein), these measurements involve sizable deuteron corrections which depend on the (unknown) ratio of the free neutron spin-flip and spin-non-flip cross sections in the dip region. If the forward dip were found to be absent at lower energies there could be profound implications for our understanding of I=0 KN scattering throughout the low energy region.

Turning next to the K^+p elastic scattering experiments in Table I, there are completed polarization measurements at 650, 700, 845, and 940 MeV/c and Coulomb interference measurements at 1.2, 1.8, and 2.6 GeV/c. The Yale-BNL results shown in Fig. 2 include the first accurate measurements of K^+p elastic polarization below 870 MeV/c. The CERN-Caen analysis includes a $K^{\pm}p$ forward dispersion relation calculation of forward real parts throughout the low energy region. These data have been used by Arndt et al.[23] in an energy dependent partial-wave analysis of K^+p elastic scattering below 2 GeV/c. The analysis uses a two-channel K-Matrix parametrization for each partial wave. The inelastic channel is $K\Delta$ in the lowest available orbital angular momentum state for all waves except S_{11} where K^*p in an S-state is used. Realistic threshold behavior reflecting the actual width of the produced resonance is included in the K-matrix elements. Arndt et al. find a Z_1^* pole in the P_{13} wave at 1797-110i MeV, poles in the P_{11}, D_{15}, F_{15}, F_{17}, and G_{17} waves with imaginary parts of 200 GeV or more, and a G_{19} pole lying closer to the physical region, 110-160 MeV, and, with a real part of 2000-2200 MeV, somewhat close to the end of the energy range considered. Only the P_{13} pole is claimed as a strong resonance candidate. This claim can not be considered conclusive because no information is given on the pole residue and its uncertainty. In particular, it is not known whether the residue differs from zero in a statistically significant way.

Of the older analyses that fit K^+p elastic data in this energy range, Martin[2] has found that his P_{13} amplitude[15] contained a pole at 1820-134i MeV, while Cutkosky et al.[24] found no pole. Martin gives no information on the residue of his pole, and since his partial-wave parametrization is only piecewise analytic, extrapolation to the pole is of questionable significance in any case. Cutkosky et al. searched for poles using a flexible parametrization which allowed comparison of fits with and without poles. No statistically significant resonance signal was found in any wave[25].

The Z_1^* therefore remains controversial, and we may ask what further measurements would be most likely to clarify the situation. Several suggestions are made by Arndt et al. They find inconsistencies among measured reaction cross sections, total cross sections, and integrated elastic cross sections, and suggest improved measurements of reaction cross sections between 0.9 and 2.0 GeV/c. They also suggest improved polarization measurements and spin-rotation parameter measurements. Regarding polarization, it would be useful to have data at even lower energies than those of Yale-BNL, to better determine the threshold behavior of the P-waves. I will consider spin-rotation measurements in some detail, because this is an area where the predictions of Arndt et al. and Cutkosky et al. differ dramatically in an experimentally attractive angular region.

A technical point worth emphasising is that a spin-rotation measurement is the measurement of a recoil polarization vector and that there is not necessarily any point in putting a lot of design effort into an attempt to measure specifically A and R rather than some other components of this vector. The components of recoil polarization to be measured should be chosen simply on considerations of optimizing the accuracy and usefulness of the results. This will primarily involve hardware considerations, but predictions of the recoil polarization from partial-wave analyses can also be profitably brought into the game. This possibility is discussed in detail in Ref. 28, and more briefly below.

The utility of recoil polarization predictions is most transparently demonstrated in terms of the Wolfenstein spin rotation angle, β, defined in Fig. 3a. On recoil from a target polarized in the scattering plane, the c.m. frame polarization is rotated through an angle β and multiplied by a factor which depends only on the ordinary polarization parameter, P. The magnitude of the recoil polarization will thus be known from the results of transversley polarized target experiments, and the task of the spin rotation experiment is to measure its orientation, i.e., β. Figure 3b shows that the component of $\underline{P}_r$ perpendicular to the predicted recoil polarization is the most sensitive measure of β provided that the prediction is not too inaccurate. As a numerical example suppose the prediction is off by 30°; then the error of β as determined from a measurement of the perpendicular component is only 15% greater than what it would be for perfect alignment while the error from a determination using the parallel component would be twice as large.

Predictions for β from Arndt et al. and Cutkosky et al. are shown in Fig. 4. There are large differences, particularly in the backward hemisphere. The uncertainties in these predictions are generally small compared to the differences between them in the energy range shown. Scattering angles near 180° are an experimentally attractive region for spin-rotation measurements. The recoil protons have plenty of momentum to emerge cleanly from the target, and emerge at sufficiently small angles so that it should be fairly easy to design polarizing coils which do not obstruct their line of flight to the analyser. For example, in the momentum range 700-1300 MeV/c, a proton scattered through 150° in the center-of-mass system emerges from the target with a lab recoil angle of about 13° and a lab recoil momentum about 140 MeV/c larger than the beam momentum.

Turning finally to the inelastic reactions in Table I, there are measurements by BGRT of $K^+p \rightarrow K^0\Delta^{++}$ and $K^+N \rightarrow K^*N$ quasi-two-body differential cross sections and density matrix elements. $KN \rightarrow K\Delta$ is an attractive channel for Z^*-hunting because the only serious candidate for a Z_1^* seen in elastic scattering (in the P_{13} wave) is highly inelastic and is known to be strongly coupled to $K\Delta$. BGRT[29] have performed an energy-dependent partial-wave analysis of $K^+p \rightarrow K^o\Delta^{++}$ below 1.5 GeV/c using the data of Ref. 14 in combination with older data. Three classes of solutions were found, all of which were dominated by P-waves, particularly PP_{13}. No evidence of resonance behavior was found in any of the three classes of solutions.

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18. The exception is the data of Ref. 4 which have been used in an energy independent analysis at 342, 470, and 587 MeV/c with deuterium effects carefully taken into account[4]. This analysis uses a pure S-wave I=1 KN amplitude at all three momenta studied, based on the results of an earlier K^+p elastic partial-wave analysis in the range 200-600 MeV/c[19]. This pure S-wave behavior disagrees with the results of the Birmingham-Rutherford analysis of K^+p elastic scattering[20] which included more data over a wider range (up to 1500 MeV/c) and found significant P_{11} P_{13} amplitudes above about 400 MeV/c.

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20. C. J. Adams et al., Nucl. Phys. B66, 36 (1973).

21. B. R. Martin, J. Phys. G: Nucl. Phys. 4, 335 (1978).

22. J. W. Alcock et al., J. Phys. G: Nucl. Phys. 4, 323 (1978).

23. R. A. Arndt et al., Virginia Polytechnic Institute and State University preprint, 1978.

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25. One may question whether the results of Cutkosky et al. are not obsolete because they did not use all of the newer data available to Arndt et al. The main new cross-section data used by Arndt et al. were those of Abe et al.[26], and it has been checked that the solution of Ref. 24 gives a quantitatively good fit to these data. The fit to the Yale-BNL polarization data has not been checked quantitatively, but Ref. 24 does predict a moderately large positive low-energy polarization in qualitative accord with the data. In fact, both Ref. 24 and Ref. 20 gave better predictions for the Yale-BNL measurements than did the original version[27] of the Arndt et al. analysis.

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Measurement	Momenta (MeV/c)	Group	Status
$K^+n \to K^+n$ DCS $K^+n \to K^0p$ DCS $K^+d \to K^+d$ DCS	252,342,470,587	Maryland-IIT	Published[4]
$K^0p \to K^+n$ DCS	550-1000	CMU-Iowa-ANL	Published[5]
$K^0p \to K^+n$ DCS	600-1500	Manchester-Daresbury	Published[6]
$K^+n \to K^0p$ DCS	700,800,900	BNL	Published[7]
$K^+n \to K^0p$ DCS	2200,2450,2700	IC-Westfield	Published[8]
$K^+n \to K^+n$ POL	700-900	BNL-Case-Western	Expt.641, BNL. Completed running 12/77.[9]
$K^+n \to K^+n$ POL $K^+n \to K^0p$ POL	860-1360	Queen Mary-Rutherford	Expt.136, RL. Completed running 4/78.[10]
$K^+n \to K^+n$ POL $K^+n \to K^0p$ POL	1300,1600,1900	KEK-Saga-Tokyo-Tsukuba-Hiroshima	Expt.34, KEK. Approved 2/76.[9]
$K^+p \to K^+p$ POL $K^+p \to K^+p$ DCS	650,700,845,940	Yale-BNL	Expt.524,BNL. Running and POL analysis completed.[11]
$K^+p \to K^+p$ 180° DCS	500-1000	LBL-Mt.Holyoke-BNL	Expt.691, BNL. In progress.[12]
$K^+p \to K^+p$ Re $f(0°)$	1209,1798,260[illegible]	CERN-Caen	*Published*[13]
$K^+p \to K^0\Delta^{++}$ DCS&DME $K^+N \to K^*N$ DCS&DME	890-1520	Bolgona-Glasgow-Rome-Trieste	Published[14]

Table I. Recent and current measurements of KN scattering below 3 GeV/c.

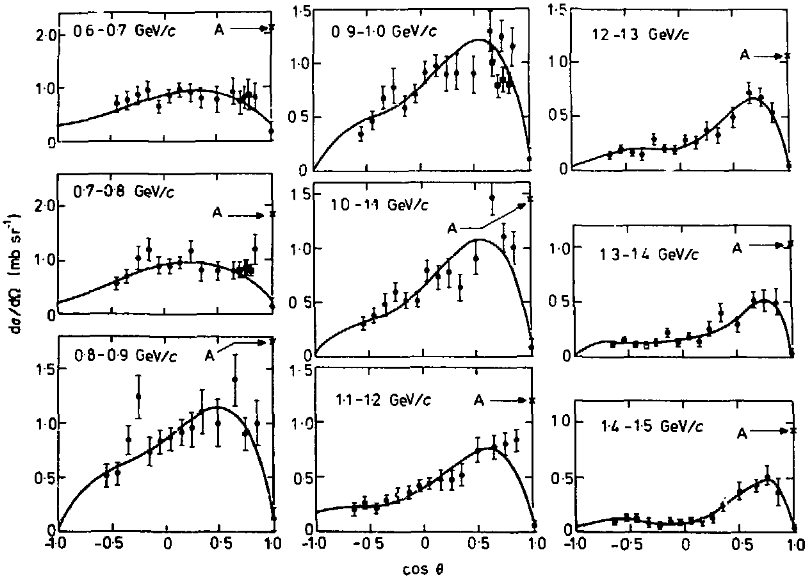

Fig.1. $K^0p \to K^+n$ differential cross section data of Armitage et al.[6] (Φ, θ≠0) and Edelstein et al.[5] (■). Also shown are threshold-subtracted forward dispersion relation predictions[21] using a conventional I=0 S-wave scattering length of −0.23 fm (Φ, θ=0), and an unconventional value of +0.7 fm (A → x) suggested by Alcock et al.[22]. The curves are Legendre fits of at most fifth order to all of the Φ data points.

XBL 788-10098

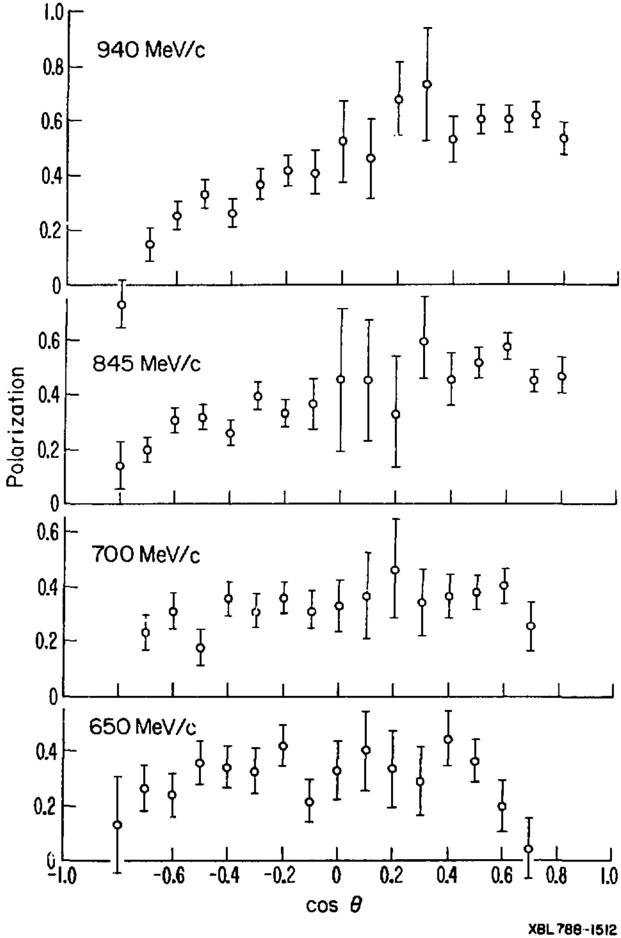

Fig. 2. K^+p elastic polarization measurements of Yale-BNL[11].

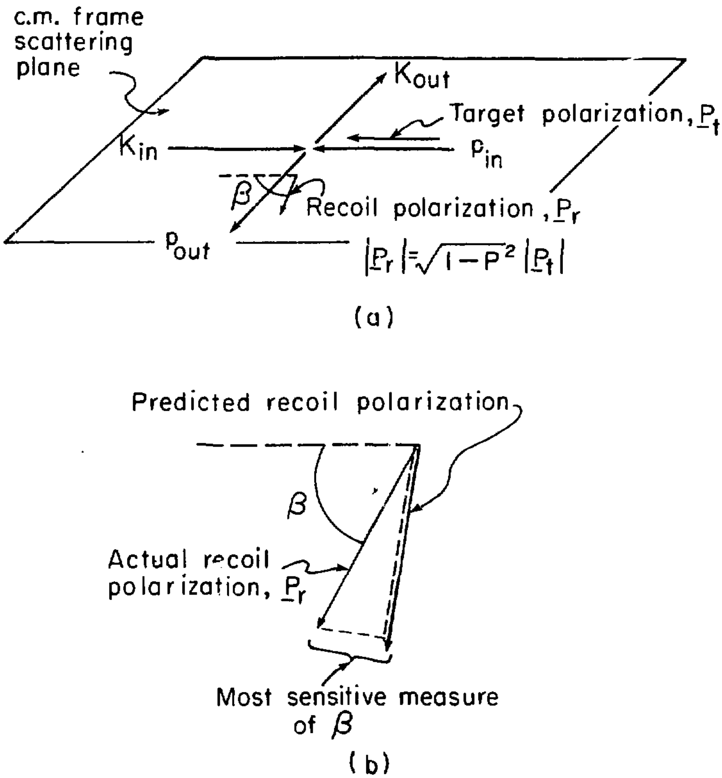

Fig. 3. (a) Definition of the Wolfenstein spin rotation angle, β. The nucleon polarization in the c.m. frame scattering plane rotates through an angle β as it recoils from the target. (b) Components of $\underline{P}_r$ with respect to its predicted value are shown as dashed lines. The component perpendicular to the predicted value is the most sensitive measure of β.

XBL 788-10097

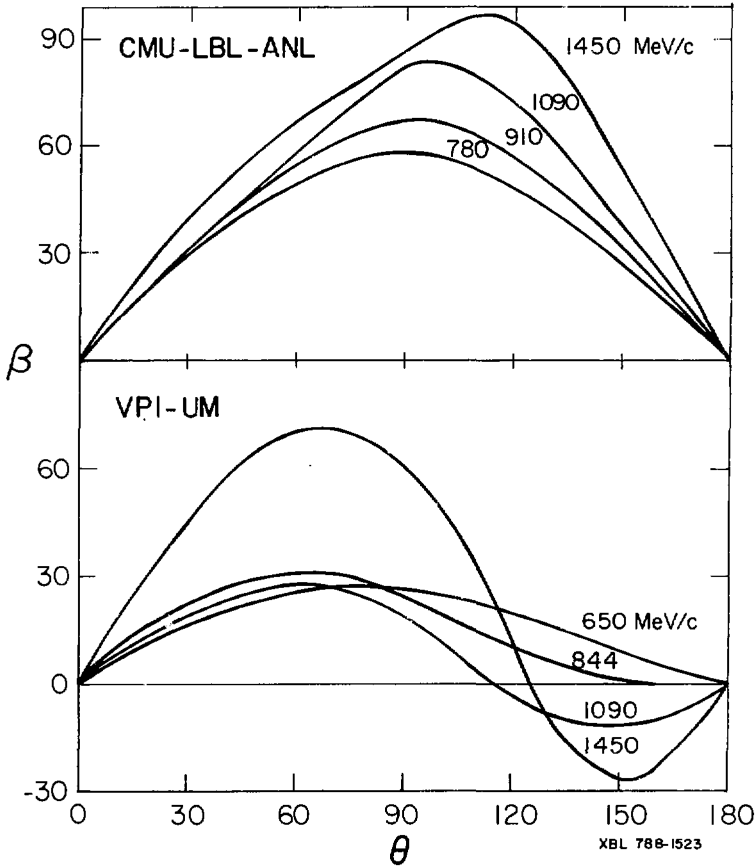

Fig. 4. Comparison of the spin-rotation angle predictions of Arndt et al.[23] (lowcr plot) and Cutkosky et al.[24] (upper plot).