Backward K^--p Scattering at 1-2 GeV/c and Resonant-State Y^*'s

SHIGEO MINAMI
Department of Physics, Osaka City University, Sumiyoshi-ku, Osaka, Japan
(Received 2 September 1966)

Backward K^--p scattering at 1–2 GeV/c is described in terms of the resonance amplitudes due to the $Y_1^*(1765)$, $Y_0^*(1815)$, $Y_1^*(1915)$, $Y_1^*(2040)$, $Y_0^*(2100)$, and $Y_1^*(2260)$. Structure of the $d\sigma/d\Omega(180°)$ for K^--p elastic scattering is predicted and the differential cross sections in the backward direction are estimated. It is shown that the experimental results for backward K^--p charge-exchange scattering at 1.2–1.7 GeV/c can be explained fairly well by the effects of the Y^*'s. Polarization of recoil nucleons in both the $K^-+p\to K^-+p$ and the $K^-+p\to \bar{K}^0+n$ reactions is predicted by taking into account the effects of the resonant states.

1. INTRODUCTION

RECENTLY, many resonant-state[1] Y^*'s in the $\bar{K}$-N system have been observed. It may easily be supposed that the Y^*'s have large effects on K^--p scattering at 1–2 GeV/c. First let us discuss K^--N scattering in the forward direction. The imaginary parts of the forward scattering amplitudes for all partial waves interfere constructively with one another and give rise to the forward peak. Therefore the resonance amplitude would not be the main part of the forward scattering amplitude. In K^--p charge-exchange scattering, on the other hand, the imaginary parts of the scattering amplitudes due to isotopic spin $I=0$ and $I=1$ states have opposite sign and interfere destructively with each other. The behavior of $d\sigma/d\Omega$ for charge-exchange scattering in the forward direction is considerably different from that of elastic scattering. Although it is said that at high energy the ρ-exchange process plays an important role in charge-exchange scattering in the forward direction, the contribution from the resonance amplitude may not be neglected.

In backward scattering, the imaginary part of the amplitude for the l wave interferes destructively with that for the $(l\pm1)$ waves. Backward meson-nucleon scattering at high energy could almost be described in terms of the resonance amplitude and the B-exchange amplitude, where the term "B-exchange amplitude" means the scattering amplitude due to the one-baryon (or B^*) exchange process. Both the resonance amplitude and the B-exchange amplitude would have large effects on backward π-p scattering, although the latter amplitude varies slowly with the energy.[2] In the description of backward K^--p elastic scattering, on the other hand, we have some favorable facts. That is, (i) there is no baryon B with strangeness $S=1$, and (ii) there is no evidence for any resonant state in the K-N system except for the resonances[3] $B_1^*(1910)$ and $B_0^*(1880)$ which seem to have been discovered recently. Even if these resonances really exist, we may suppose from experimental data[3] for σ_1 and σ_0 that the effects of one-B^* exchange on backward K^--p elastic scattering are not so large. These facts (i) and (ii) make our description of backward K^--p scattering particularly simple. Needless to say, the resonance amplitude is mainly responsible for the structure of the cross section at 180°. In Sec. 2, the structure of $d\sigma/d\Omega(180°)$ for K^--p elastic scattering at 1-2 GeV/c is predicted by taking into account the effects of the resonances $Y_1^*(1765)$, $Y_0^*(1815)$, $Y_1^*(1915)$, $Y_1^*(2040)$, $Y_0^*(2100)$, and $Y_1^*(2260)$ which have been discovered recently. The results are the following: $d\sigma/d\Omega(180°)$ has a maximum and a minimum at $p\cong1.7$ and 1.2 GeV/c, respectively, and some structure in a region 1.3–1.5 GeV/c. In order to examine the behavior of $d\sigma/d\Omega$ near 180°, differential cross sections of backward K^--p elastic scattering at 1.2, 1.5, and 1.7 GeV/c are estimated in Sec. 3. The behavior of $d\sigma/d\Omega$ in the backward region depends strongly on the energy. That is, $d\sigma/d\Omega$ at 1.2 or 1.5 GeV/c has a maximum value in the neighborhood of $\cos\theta=-0.85$, while $d\sigma/d\Omega$ at 1.7 GeV/c has a backward peak.

According to the experimental data[4] for K^--p charge-exchange scattering from 1.2 to 1.7 GeV/c, a peripheral mechanism is insufficient to reproduce the experimental angular distribution. It would be necessary to take the effects of the Y^*'s into consideration. In Sec. 4, K^--p charge-exchange scattering at 1.22, 1.51, and 1.7 GeV/c is described in terms of the resonance amplitudes due to the $Y_1^*(1765)$, $\cdots$, $Y_0^*(2100)$, and $Y_1^*(2260)$. By such a treatment it is possible to explain fairly well the experimental results[4] for the angular distribution in the backward direction, particularly (i) the decline of a sharp backward peak as a function of increasing mo-

[1] For detailed references, see A. H. Rosenfeld, A. Barbaro-Galtieri, W. H. Barkas, P. L. Bastien, J. Kirz, and M. Roos, Rev. Mod. Phys. **37**, 633 (1965); input data and references for the four August 1966 Particle and Resonance Tables.

[2] Recently Kormanyos *et al.* have measured the differential cross section for backward π^--p elastic scattering in an energy region 1.6–5.3 GeV/c and have reported some interesting results for structure of the $d\sigma/d\Omega(180°)$: S. W. Kormanyos, A. D. Krisch, J. R. O'Fallon, K. Ruddick, and L. G. Ratner, Phys. Rev. Letters **16**, 709 (1966).

[3] R. L. Cool, G. Giacomelli, T. F. Kycia, B. A. Leontić, K. K. Li, A. Lundby, and J. Teiger, Phys. Rev. Letters **17**, 102 (1966).

[4] C. G. Wohl, University of California, Lawrence Radiation Laboratory Report No. UCRL-16288 1965 (unpublished); M. Ferro-Luzzi, F. T. Solmitz, and M. L. Stevenson, in *Proceedings of the 1962 International Conference on High Energy Physics at CERN*, edited by J. Prentki (CERN, Geneva, 1962), p. 376; C. G. Wohl, F. T. Solmitz, and M. L. Stevenson, Bull. Am. Phys. Soc. **10**, 529 (1965).

TABLE I. Experimental data and values of the parameters for each resonance (Refs. 1, 6).

Resonance	J^P	l	Γ (MeV)	Γ_K (MeV)	Elasticity
$Y_1^*(1765)$	$\frac{5}{2}^-$	2	75	45	0.6
$Y_0^*(1815)$	$\frac{5}{2}^+$	3	50	37.5	0.75
$Y_1^*(1915)$	$\frac{5}{2}^+$	3	65	6.7	0.103
$Y_1^*(2040)$	$\frac{7}{2}^+$	3	150	23.3	0.155
$Y_0^*(2100)$	$\frac{7}{2}^-$	4	160	46.4	0.29
$Y_1^*(2260)$	$\frac{9}{2}^-$	4	180	16.4	0.091

mentum and (ii) the two intermediate bumps. In Sec. 5, the polarization $P(\theta)$ of recoil nucleons in both $K^-+p\to K^-+p$ and $K^-+p\to \bar{K}^\circ+n$ scattering in the backward direction is predicted by taking into account the effects of the Y^*'s. The results show a remarkable difference between the features of $P(\theta)$ in the two reactions at about 1.7 GeV/c.

2. K^--p ELASTIC SCATTERING AT 180°

We now think it worthwhile to predict the structure of $d\sigma/d\Omega(180°)$ for K^--p elastic scattering at 1-2 GeV/c. In the description of K^--p elastic scattering at 180°, the B-exchange amplitude would be so small in magnitude that it may be neglected compared with the resonance amplitude for the following reasons (i) There is no baryon B with strangeness $S=1$. (ii) Needless to say, the $B_0^*(1880)$ in the K-N system does not contribute to the B-exchange amplitude for $K^-+p\to K^-+p$ scattering, but to that for $K^-+p\to\bar{K}^\circ+n$ scattering.[5] According to the experimental data,[3] the peak of total cross section σ_1 for K^+-p scattering due to the $B_1^*(1910)$ is not so pronounced and the $B_1^*(1910)$ seems to be an inelastic resonance. Then, it is impossible to expect a large effect of the $B_1^*(1910)$ on $d\sigma/d\Omega$ (180°) for the $K^-+p\to K^-+p$ reaction. Since the incident K^- laboratory momenta 1 and 2 GeV/c correspond, respectively, to the total energies $\omega=1793$ and 2233 MeV, in this paper we try to describe $d\sigma/d\Omega(180°)$ in terms of the resonance amplitudes due to the $Y_1^*(1765)$, $Y_0^*(1815)$, $Y_1^*(1915)$, $Y_1^*(2040)$, $Y_0^*(2100)$, and $Y_1^*(2260)$.

When the S matrix for the state $J=l+\frac{1}{2}(J=l-\frac{1}{2})$ responsible for the resonant state Y^* is expressed by $\eta_l^+\exp(2i\delta_l^+)[\eta_l^-\exp(2i\delta_l^-)]$,

$$R_l^\pm\equiv S_l^\pm-1=\eta_l^\pm\exp(2i\delta_l^\pm)-1=\frac{-i\Gamma_K}{(\omega-\omega_r)+i\Gamma/2} \quad (1)$$

and

$$f_R(180°)=\tfrac{1}{2}(i/2k)[1-\eta_l^\pm\exp(2i\delta_l^\pm)]\times(J+\tfrac{1}{2})(-1)^l, \quad (2)$$

where ω_r is the resonance energy, Γ and Γ_K are, respectively, the total width and the partial width of the resonance into the channel $\bar{K}+N$, $f_R(180°)$ represents the resonance amplitude at 180° for the $K^-+p\to K^-+p$ due to the resonant state, and the first factor $\frac{1}{2}$ in Eq. (2) comes from isotopic spin for the K^--p system.

[5] For this point, see Ref. 14.

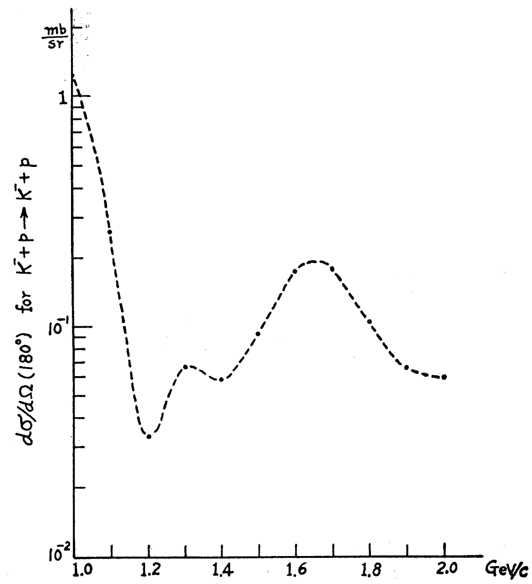

FIG. 1. Theoretical values for $d\sigma/d\Omega(180°)$ for elastic scattering at 1–2 GeV/c.

Cool *et al.*[6] have found new structure in the K^--p and K^--d total cross sections and have tried to make the spin-parity assignment to the resonant-state Y^*'s (cf. Table I) on the basis of a Regge-recurrence model. When the masses squared of $Y_1^*(1385)$, $Y_1^*(1765)$, $Y_1^*(2040)$, and $Y_1^*(2260)$ [the $\Lambda(1115)$, $Y_0^*(1520)$, $Y_0^*(1815)$, and $Y_0^*(2100)$] are plotted as a function of spin, we can see that the assumption of approximate straight-line trajectories with similar slopes is consistent with experimental data. In this paper we adopt the spin-parity assignment based on the Regge-pole theory (cf. Table I) and study backward K^--p scattering at 1-2 GeV/c. The resonance amplitude due to each resonance depends, of course, on the values of parameters for the resonance, particularly on the magnitude of its elasticity, the resonance energy, the value of l, and whether l is even or odd, where l is the partial wave responsible for the resonance. By using the experimental data[1] and assumed parameter values for the Y^*'s (see Table I), $d\sigma/d\Omega(180°)$ for K^--p elastic scattering at 1-2 GeV/c can be calculated. The results are shown in Fig. 1.

It may be necessary to examine contributions from the Y^*'s whose masses are less than 1.7 GeV and are larger than (m_N+m_K). We try to estimate here the effects of the observed $Y_0^*(1520)$ and $Y_1^*(1660)$ on $d\sigma/d\Omega(180°)$ at 1.2 and 1.7 GeV/c. According to recent experimental data,[1] the width Γ and elasticity x of the former resonance are nearly equal to 16 MeV and 0.29,

[6] R. L. Cool, G. Giacomelli, T. F. Kycia, B. A. Leontic, K. K. Li, A. Lundby, and J. Teiger, Phys. Rev. Letters **16**, 1228 (1966).

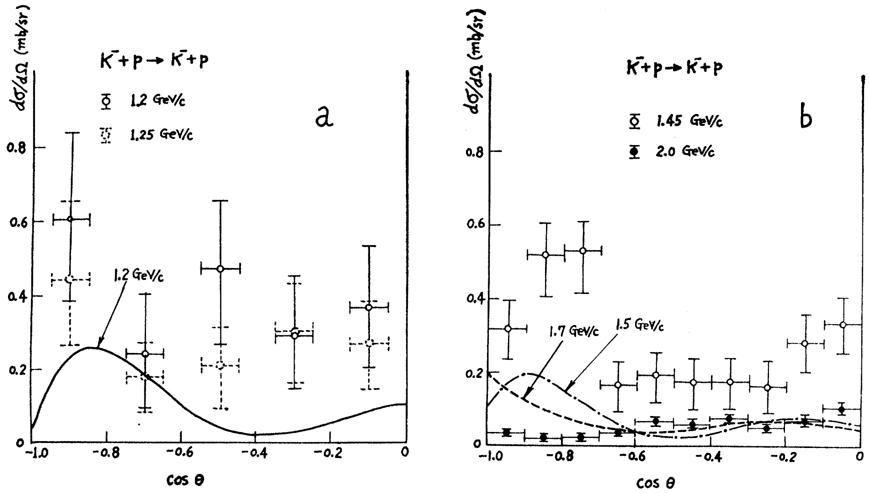

FIG. 2. Differential cross sections for K^--p elastic scattering in the backward direction. The solid, dash-dot, and dashed curves show theoretical values of $d\sigma/d\Omega$ at 1.2, 1.5, and 1.7 GeV/c, respectively. The experimental data at 1.2 and 1.25 GeV/c are from Ref. 11, and those at 1.45 and 2.0 GeV/c are from Refs. 12 and 13, respectively.

respectively, and those for the latter resonance[7] are $\Gamma\cong 50$ MeV and $x\cong 0.15$. Then we get the following results:

$$f(1520)\cong\begin{cases}(1/k)(0.0001i-0.0063) & \text{for } 1.2\ \text{GeV}/c\\ (1/k)(0.0000i-0.0039) & \text{for } 1.7\ \text{GeV}/c,\end{cases}$$

and

$$f(1660)\cong\begin{cases}(1/k)(0.0018i-0.0163) & \text{for } 1.2\ \text{GeV}/c\\ (1/k)(0.0005i-0.0083) & \text{for } 1.7\ \text{GeV}/c,\end{cases}\qquad(3)$$

where $f(M)$ indicates the contribution from a resonance $Y^*(M)$ to $f_R(180°)$. Since the values of $f(2100)$ at 1.2 and 1.7 GeV/c are nearly equal to $(0.0717i+0.1909)/k$ and $(0.5743i-0.0574)/k$, respectively, the effects of $Y_0^*(1520)$ and $Y_1^*(1660)$ on $f_R(180°)$ can be neglected compared with those of $Y_0^*(2100)$.

As is seen from Fig, 1, $d\sigma/d\Omega(180°)$ has a maximum value and a minimum value in the neighborhood of $p=1.7$ and 1.2 GeV/c, respectively. Since the incident K^- laboratory momenta 1.7 and 1.2 GeV/c correspond, respectively, to the total energies $\omega=2108$ and 1887 MeV, it may be expected that $Y_0^*(2100)$ and $Y_1^*(1915)$ have large effects on backward K^--p elastic scattering at 1.7 and 1.2 GeV/c, respectively. Because of the large value of Γ_K for the $Y_0^*(2100)$, needless to say, the peak at about 1.7 GeV/c is associated with the $Y_0^*(2100)$. The value of Γ_K for the $Y_1^*(1915)$, on the other hand, is very small (see Table I). So the resonance amplitude due to the $Y_1^*(1915)$ contributes to $d\sigma/d\Omega(180°)$ at 1.2 GeV/c, with the same order of magnitude as those due to the lower or higher mass resonances. Some of the resonance amplitudes have a positive sign, others a negative sign, which helps to cancel their effects. This would be the reason why $d\sigma/d\Omega(180°)$ has a minimum value in the neighborhood of $p=1.2$ GeV/c. According to experimental data,[8] the total cross section σ_{total} for K^--p scattering at 1.7 GeV/c is nearly equal to or slightly larger than σ_{total} at 1.2 GeV/c. Thus we can say that when the value of the elasticity is not so small, the existence of a resonant state will be reflected strongly in the behavior of $d\sigma/d\Omega(180°)$ for K^--p elastic scattering rather than that of the total cross section.

3. DIFFERENTIAL CROSS SECTIONS OF BACKWARD K^--p ELASTIC SCATTERING AT 1.2, 1.5, AND 1.7 GeV/c

In view of the results for $d\sigma/d\Omega(180°)$ mentioned in Sec. 2, we are interested in the behavior of $d\sigma/d\Omega$ near 180°, particularly in that of elastic scattering at 1.2 and 1.7 GeV/c. In this section, the differential cross sections of backward K^--p elastic scattering at 1.2, 1.5, and 1.7 GeV/c are estimated by taking into account the effects of the resonant-state $Y_1^*(1765),\cdots$, $Y_0^*(2100)$, and $Y_1^*(2260)$. As is well known, the differential cross section of K^--p elastic scattering can be expressed by[9,10]

$$\begin{aligned}4k^2\sin^2\theta(d\sigma/d\Omega)=&\tfrac{1}{4}\sum_{l,l'}(l+1)(l'+1)\\ &\times\{(R_l^+R_{l'}^{+*}+R_{l+1}^-R_{l'+1}^{-*})[P_lP_{l'}+P_{l+1}P_{l'+1}\\ &-\cos\theta(P_lP_{l'+1}+P_{l+1}P_{l'})]+(R_l^+R_{l'+1}^{-*}+R_{l+1}^-R_{l'}^{+*})\\ &\times[P_lP_{l'+1}+P_{l+1}P_{l'}-\cos\theta(P_lP_{l'}+P_{l+1}P_{l'+1})]\},\end{aligned}\qquad(4)$$

where R_l^+ and R_l^- are the R matrices for the states $J=l+\frac{1}{2}$ and $J=l-\frac{1}{2}$, respectively, and the first factor $\frac{1}{4}$ on the right-hand side comes from isotopic spin of the K^--p system. Using this general expression for the $d\sigma/d\Omega$, we can easily calculate the effect of each resonant

[7] It seems that the spin-parity J^P of the $Y_1^*(1660)$ has not yet been established. We assume here that the $Y_1^*(1660)$ has $J^P=\frac{3}{2}^-$. In the case of $J^P=\frac{3}{2}^+$, the $f(1660)$ has the opposite sign to that in Eq. (3). Even if the spin of the $Y_1^*(1660)$ is equal to $\frac{5}{2}$, the magnitude of $f(1660)$ is still so small that it may be neglected compared with that of $f(2100)$.

[8] L. T. Kerth, Rev. Mod. Phys. **33**, 389 (1961).

[9] S. Minami, Progr. Theoret. Phys. (Kyoto) **11**, 213 (1954).

[10] S. Hayakawa, M. Kawaguchi, and S. Minami, Progr. Theoret. Phys. (Kyoto) **12**, 355 (1954).

state. Since the $Y_0^*(1815)$ and $Y_1^*(1915)$ have the same spin parity $J^P=\frac{5}{2}^+$, the R_3^- in our description of $K^-+p\rightarrow K^-+p$ scattering is the sum of the R matrices for the states associated with these resonances. Our result indicates that the angular distribution in the backward direction depends strongly on the energy. That is, $d\sigma/d\Omega$ at 1.7 GeV/c has a backward peak, while $d\sigma/d\Omega$ at 1.2 or 1.5 GeV/c has a maximum value in the neighborhood of $\cos\theta=-0.85$ (see Fig. 2). As was emphasized in Sec. 2, the $Y_0^*(2100)$ plays the most important role in backward K^--p elastic scattering at 1.7 GeV/c. The effect due to the state $J^P=\frac{7}{2}^-$ contributes to $d\sigma/d\Omega$ with a form $R_4^{-*}R_4^-(9+45\cos^2\theta-165\cos^4\theta+175\cos^6\theta)/4$. One of the most important characters of this form is a sharp backward peak. Our results for $d\sigma/d\Omega$ at 1.7 GeV/c show the characteristic aspect, although contributions from the other states cannot be neglected.

Because the value of Γ_K for the $Y_0^*(2100)$ is much larger than that for the $Y_1^*(2040)$, the effects of the former resonance on K^--p elastic scattering at 1.5 GeV/c ($\omega\cong 2021$ MeV) are comparable to those of the latter resonance. The main properties of angular distribution at 1.5 GeV/c are described in terms of the R matrices R_4^- and R_3^+ for the states associated with these resonances. The term $(R_3^{+*}R_3^+ + R_4^{-*}R_4^-)$ in Eq. (4) gives the angular distribution with a backward peak, and the term $(R_3^{+*}R_4^- + R_4^{-*}R_3^+)$ gives the angular distribution $(-81\cos\theta+795\cos^3\theta-1875\cos^5\theta+1225\cos^7\theta)/4$, which has a minimum at $\cos\theta\cong -0.55$ and maxima in the neighborhood of $\cos\theta=-0.85$ and -0.2. The $\cos\theta$ dependence of the interference term $(R_3^{+*}R_4^- + R_4^{-*}R_3^+)$ is much stronger than that of $(R_3^{+*}R_3^+ + R_4^{-*}R_4^-)$. We can see the qualitative features of the interference effect in our results for $d\sigma/d\Omega$ at 1.5 GeV/c [see Fig. 2(b)].

In K^--p elastic scattering at 1.2 GeV/c, R_3^- among the R matrices is the largest in magnitude, because $p=1.2$ GeV/c corresponds to $\omega=1887$ MeV and because R_3^- is the sum of the R matrices for the states associated with the $Y_0^*(1815)$ and $Y_1^*(1915)$. As was mentioned in Sec. 2, however, contributions from the other states are too large in magnitude to be neglected. The $\sum_n a_n\cos^{2n}\theta$ and $\sum_n b_n\cos^{2n+1}\theta$ terms in the expression for $d\sigma/d\Omega$ at 1.2 GeV/c have maximum values at about $\cos\theta=-0.9$ and $\cos\theta=-0.8$, respectively. This gives rise to a maximum of $d\sigma/d\Omega$ in the neighborhood of $\cos\theta=-0.85$.

Now let us compare our results with the experimental data.[11–13] The theoretical cross sections at 1.2 GeV/c are considerably smaller than the observed ones [cf. Fig. 2(a)]. As is shown in Fig. 2(b), the experimental values of $d\sigma/d\Omega$ in the backward direction seem to depend strongly on the incident energy in a region 1.45−2.0 GeV/c. In the case of $p=2.0$ GeV/c, the value of $d\sigma/d\Omega(180°)\cong 0.06$ mb/sr estimated in Sec. 2 is much larger than the experimental cross section at $\cos\theta=(-0.9)$-(-1.0) ($d\sigma/d\Omega=0.025\pm0.009$ mb/sr) which has been reported by Crittenden *et al.*[13] From the experimental angular distribution at 1.45 GeV/c,[12] we can see the following qualitative features: (i) $d\sigma/d\Omega$ has maxima in the neighborhood of $\cos\theta=-0.8$ and -0.1. (ii) $d\sigma/d\Omega$ has a minimum at about $\cos\theta=0.1$ (see Fig. 2 in Ref. 12) and has small values in a region from $\cos\theta=-0.3$ to -0.6. These characteristic properties of $d\sigma/d\Omega$ in the backward region can be described fairly well in terms of the direct resonance amplitudes.

Since the backward peak of $d\sigma/d\Omega$ at 1.7 GeV/c is one of the most important characteristics, we hope to get detailed experimental data for elastic K^--p scattering at 1.7 GeV/c.

4. K^--p CHARGE-EXCHANGE SCATTERING AT 1.2–1.7 GeV/c

The recent experiment[4] for K^--p charge-exchange scattering at 1.2–1.7 GeV/c has indicated the following remarkable results: (i) There is a sharp backward peak in the $d\sigma/d\Omega$ at 1.22 GeV/c. As the incident K^- momentum increases, the sharp backward peak declines and a blunt forward peak rises. (ii) The angular distribution has the two intermediate bumps. The bumps have a tendency to move slowly backward with increasing momentum. (iii) Though the forward peaking at the higher momenta is considerable, a peripheral mechanism is by itself insufficient to reproduce the experimental angular distribution. In order to examine whether or not the experimental results (i) and (ii) can be explained by the effects of the Y^*'s, we study in this section K^--p charge-exchange scattering at 1.22, 1.51, and 1.7 GeV/c, along the same line as the approach in Sec. 3.

In our description of K^--p charge-exchange scattering, we have only to pay attention to the following point: Since the K^--p scattering amplitudes are expressed by

$$A(K^-+p\rightarrow \bar{K}^\circ+n)=\tfrac{1}{2}[A(I=1)-A(I=0)],\quad (5)$$

$$A(K^-+p\rightarrow K^-+p)=\tfrac{1}{2}[A(I=1)+A(I=0)],\quad (6)$$

the R matrix for the state associated with the Y_0^* contributes to the $A(K^-+p\rightarrow\bar{K}^\circ+n)$ and $A(K^-+p\rightarrow K^-+p)$ with opposite sign, where $A(I=0)$ and $A(I=1)$ are the elastic-scattering amplitudes in the pure isotopic-spin states. Therefore, R_4^- for the $K^-+p\rightarrow\bar{K}^\circ+n$ reaction has opposite sign to that for the $K^-+p\rightarrow K^-+p$ reaction, and R_3^- for the former reaction is expressed by the difference between the

[11] E. F. Beall, W. Holley, D. Keefe, L. T. Kerth, J. J. Thresher, C. L. Wang, and W. A. Wenzel, in *Proceedings of 1962 Annual International Conference on High-Energy Nuclear Physics at CERN*, edited by J. Prentki (CERN, Geneva, 1962), p. 368.

[12] A. Fridman, O. Benary, A. Michalon, B. Schiby, R. Strub, and G. Zech, Phys. Rev. **145**, 1136 (1966).

[13] R. Crittenden, H. J. Martin, W. Kernan, L. Leipuner, A. C. Li, F. Ayer, L. Marshall, and M. L. Stevenson, Phys. Rev. Letters **12**, 429 (1964).

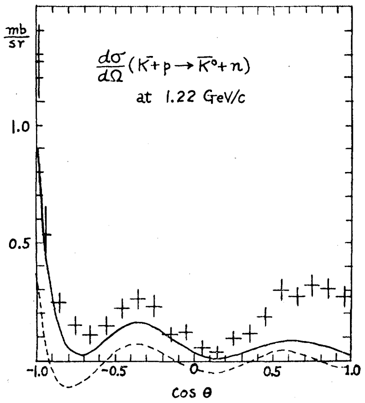

FIG. 3. Differential cross section for K^--p charge-exchange scattering at 1.22 GeV/c. The experimental data are from Ref. 4. The solid curve shows our results for $d\sigma/d\Omega$. The dashed curve shows contributions from the interference terms $(R_2^{+*}R_3^- + R_3^{-*}R_2^+)$, $[(R_2^{+*}R_4^- + R_4^{-*}R_2^+) + (R_3^{-*}R_3^+ + R_3^{+*}R_3^-)]$, and $(R_4^{-*}R_4^+ + R_4^{+*}R_4^-)$ to $d\sigma/d\Omega$.

R matrices for the states associated with the $Y_1^*(1915)$ and $Y_0^*(1815)$. In addition, it may be supposed from relation (5) that the effects of nonresonant background turn out to be small, particularly in the backward direction.

In Figs. 3, 4, and 5 are shown the results for $d\sigma/d\Omega$ at 1.22, 1.51, and 1.7 GeV/c. If the amplitude for K^--p elastic scattering near 180° has small values on account of a destructive interference between $A(I=1)$ and $A(I=0)$ such as the $A(K^- + p \to K^- + p)$ at 1.2 GeV/c, it may be expected that the amplitude for K^--p charge-exchange scattering near 180° has large values and that $d\sigma/d\Omega(K^- + p \to \bar{K}^\circ + n)$ has a pronounced backward peak at about 1.2 GeV/c. The characteristic feature of $d\sigma/d\Omega$ for K^--p charge-exchange scattering at 1.2 GeV/c mainly comes from the interference terms $(R_2^{+*}R_3^- + R_3^{-*}R_2^+)$,

$$[(R_2^{+*}R_4^- + R_4^{-*}R_2^+) + (R_3^{-*}R_3^+ + R_3^{+*}R_3^-)],$$

and $(R_4^{-*}R_4^+ + R_4^{+*}R_4^-)$ (see the dashed curve in Fig. 3). As is seen from Fig. 3, the two intermediate

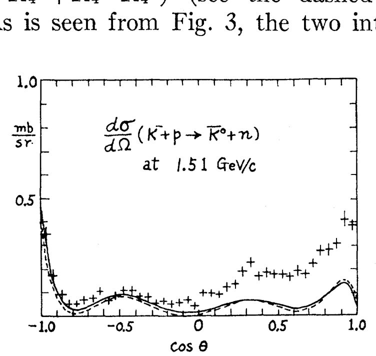

FIG. 4. Differential cross section for K^--p charge-exchange scattering at 1.51 GeV/c. The experimental data are from Ref. 4. The solid curve shows our results for $d\sigma/d\Omega$. The dashed curve shows contributions from the terms $(R_3^{+*}R_3^+ + R_4^{-*}R_4^-)$,

$$[(R_2^{+*}R_4^- + R_4^{-*}R_2^+) + (R_3^{-*}R_3^+ + R_3^{+*}R_3^-)],$$

$(R_3^{+*}R_4^- + R_4^{-*}R_3^+)$, and $(R_4^{-*}R_4^+ + R_4^{+*}R_4^-)$ to $d\sigma/d\Omega$.

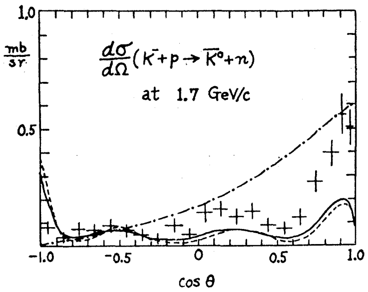

FIG. 5. Differential cross section for K^--p charge-exchange scattering at 1.7 GeV/c. The experimental data and the dash-dot curve (prediction of the simple ρ-exchange model) are from Ref. 4. The solid curve shows our results for $d\sigma/d\Omega$. The dashed curve shows contributions from the terms $(R_3^{+*}R_3^+ + R_4^{-*}R_4^-)$, $(R_3^{+*}R_4^- + R_4^{-*}R_3^+)$, and $(R_4^{-*}R_4^+ + R_4^{+*}R_4^-)$ to $d\sigma/d\Omega$.

bumps at about $\cos\theta = -0.4$ and $\cos\theta = 0.6$ are due to the effects of these terms. In the case of $K^- + p \to \bar{K}^\circ + n$ scattering, the terms have signs opposite to those in case of $K^- + p \to K^- + p$ scattering. This is the reason why, in our estimation, $d\sigma/d\Omega(K^- + p \to \bar{K}^\circ + n)$ at 1.22 GeV/c has a sharp backward peak, while $d\sigma/d\Omega$-$(K^- + p \to K^- + p)$ at 1.2 GeV/c has small values near 180°.

The backward peak of $d\sigma/d\Omega$ at 1.51 GeV/c is also mainly attributed to the interference effect between the amplitudes $A(I=1)$ and $A(I=0)$. Note that in Fig. 4 the properties of the solid curve are similar to those of the dashed curve. This means that the angular distribution with the two bumps at about $\cos\theta = -0.5$ and $\cos\theta = 0.3$ and with a blunt forward peak comes from the effects of the terms $(R_3^{+*}R_3^+ + R_4^{-*}R_4^-)$,

$$[(R_2^{+*}R_4^- + R_4^{-*}R_2^+) + (R_3^{-*}R_3^+ + R_3^{+*}R_3^-)],$$
$$(R_3^{+*}R_4^- + R_4^{-*}R_3^+), \text{ and } (R_4^{-*}R_4^+ + R_4^{+*}R_4^-).$$

Since the $Y_0^*(2100)$ plays the most important role in K^--p scattering at about 1.7 GeV/c, the backward peak at 1.7 GeV/c is mainly due to strong interaction in the $J^P = \frac{7}{2}^-$ state. As is seen from Fig. 5, the terms $(R_3^{+*}R_3^+ + R_4^{-*}R_4^-)$, $(R_3^{+*}R_4^- + R_4^{-*}R_3^+)$, and $(R_4^{-*}R_4^+ + R_4^{+*}R_4^-)$ are responsible for the qualitative features of the angular distribution at 1.7 GeV/c, particularly the backward peak, the two intermediate bumps and a blunt forward peak, although the bumps are not so pronounced.

On the basis of our results illustrated in Figs. 3, 4, and 5, we can say the following: So far as backward K^--p charge-exchange scattering at 1.2–1.7 GeV/c is concerned, the experimental results[4] can be explained fairly well by the effects of the resonant-state Y^*'s.[14] Although our results show a blunt forward peak at the

[14] In other words, even if the resonance B^*'s really exist, the B-exchange amplitude due to the one-$B_0^*(1880)$-exchange and one-$B_1^*(1910)$-exchange processes has no large effect on backward K^--p charge-exchange scattering at 1.2–1.7 GeV/c.

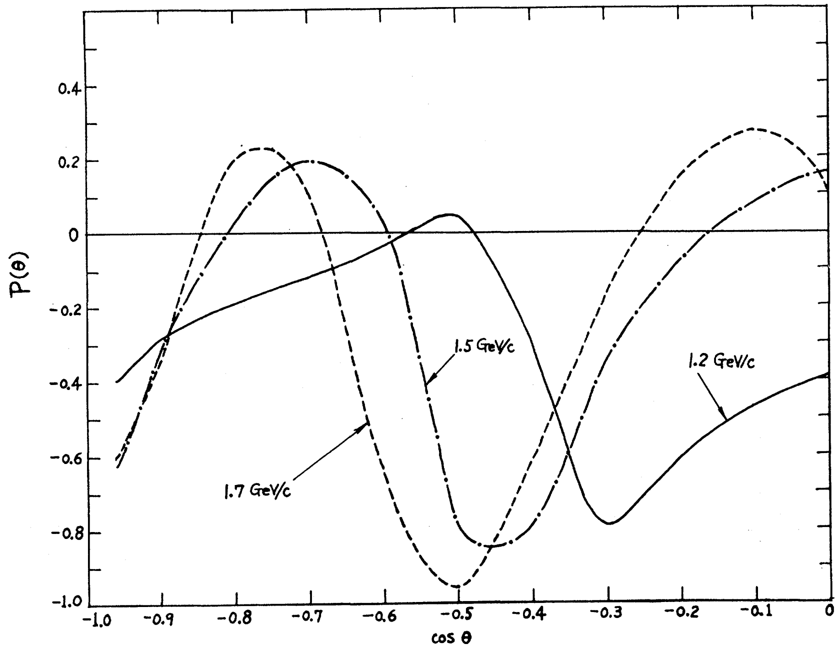

FIG. 6. Theoretical curves for polarization $P(\theta)$ of recoil nucleons in backward K^--p elastic scattering. The solid, dash-dot, and dashed curves show the values of $P(\theta)$ at 1.2, 1.5, and 1.7 GeV/c, respectively.

higher momenta, the magnitude of $d\sigma/d\Omega$ in the forward direction is too small to explain the experimental data.[15]

5. POLARIZATION OF RECOIL NUCLEONS IN BACKWARD K^--p SCATTERING

In this section, the polarization of recoil nucleons in both the $K^-+p\rightarrow K^-+p$ and the $K^-+p\rightarrow \bar{K}^\circ+n$ reactions is predicted by taking into account the effects of the resonant-state Y^*'s. In view of the large difference between $d\sigma/d\Omega(K^-+p\rightarrow K^-+p)$ and $d\sigma/d\Omega$-$(K^-+p\rightarrow \bar{K}^\circ+n)$ in the backward direction, we may expect also a large difference between the qualitative features of polarization in the two reactions. The polarization of recoil nucleons in K^--p scattering can be expressed by[10]

$$\mathfrak{P}=(X/Y)\mathfrak{n},\quad (n=\mathbf{K}_f\times\mathbf{K}_i/|\mathbf{K}_f\times\mathbf{K}_i|),\tag{7}$$

$$Y=d\sigma/d\Omega,\tag{8}$$

$$\begin{aligned}(4k^2\sin\theta)X=\frac{i}{4}\sum_{l,l'}(l+1)(l'+1)\\ \times[(R_l^+R_{l'}^{+*}-R_{l+1}^-R_{l'+1}^{-*})(P_lP_{l'+1}-P_{l+1}P_{l'})\\ +(R_l^+R_{l'+1}^{-*}-R_{l+1}^-R_{l'}^{+*})(P_lP_{l'}-P_{l+1}P_{l'+1})].\end{aligned}\tag{9}$$

By using the values of the R matrices obtained in Secs. 3 and 4, we can easily estimate the polarization of recoil nucleons in both the $K^-+p\rightarrow K^-+p$ and the $K^-+p\rightarrow \bar{K}^\circ+n$ reactions.

In Figs. 6 and 7 are shown our results for the former and the latter reactions, respectively. In the case of $p=1.2$ GeV/c, the magnitude of the polarization $P(\theta)$ in $K^-+p\rightarrow \bar{K}^\circ+n$ scattering is pretty small in a region from $\cos\theta=-0.2$ to $\cos\theta=-0.4$, while $P(\theta)$ in $K^-+p\rightarrow K^-+p$ scattering has large values with negative sign in the same $\cos\theta$ region. In the case of $p=1.5-1.7$ GeV/c, the behavior of $P(\theta)$ in the $K^-+p\rightarrow \bar{K}^\circ+n$ is in interesting contrast with that of $P(\theta)$ in the $K^-+p\rightarrow K^-+p$. When the X in Eq. (9) is expressed by

$$X=(-\sin\theta)(\sum_{n=0}^{7}B_n\cos^n\theta)/64k^2,$$

the coefficients B_n have the following values at 1.7 GeV/c, for example:

For $K^-+p\rightarrow K^-+p$ at 1.7 GeV/c,

$B_0=-0.41$, $B_1=15.66$, $B_2=43.91$, $B_3=-162.15$, $B_4=-176.24$, $B_5=394.93$, $B_6=170.62$, $B_7=-267.92$.

For $K^-+p\rightarrow \bar{K}^\circ+n$ at 1.7 GeV/c,

$B_0=1.46$, $B_1=-17.55$, $B_2=-47.48$, $B_3=170.78$, $B_4=191.95$, $B_5=-406.71$, $B_6=-183.99$, $B_7=267.92$.

Here we wish to emphasize that there is no large difference between the values of each $|B_n|$ for both reactions and that the sign of each B_n for the $K^-+p\rightarrow K^-+p$ reaction is opposite to that for the $K^-+p\rightarrow \bar{K}^\circ+n$ reaction. This can be interpreted as follows: The main feature of $P(\theta)$ in K^--p scattering at 1.7 GeV/c can be described in terms of the interference effects $(R_3^{+*}R_4^- - R_4^{-*}R_3^+)$ and $(R_4^{-*}R_4^+ - R_4^{+*}R_4^-)$ [see Eq. (9)]. Because of relations (5) and (6), the R_4^- for the state associated with the $Y_0^*(2100)$ contributes to the $K^-+p\rightarrow K^-+p$ and $K^-+p\rightarrow \bar{K}^\circ+n$ reactions with opposite sign. Therefore the interference effects for the two reactions have the same magnitude

[15] It may be expected that this situation would be improved when effects of the ρ-exchange process are taken into consideration.

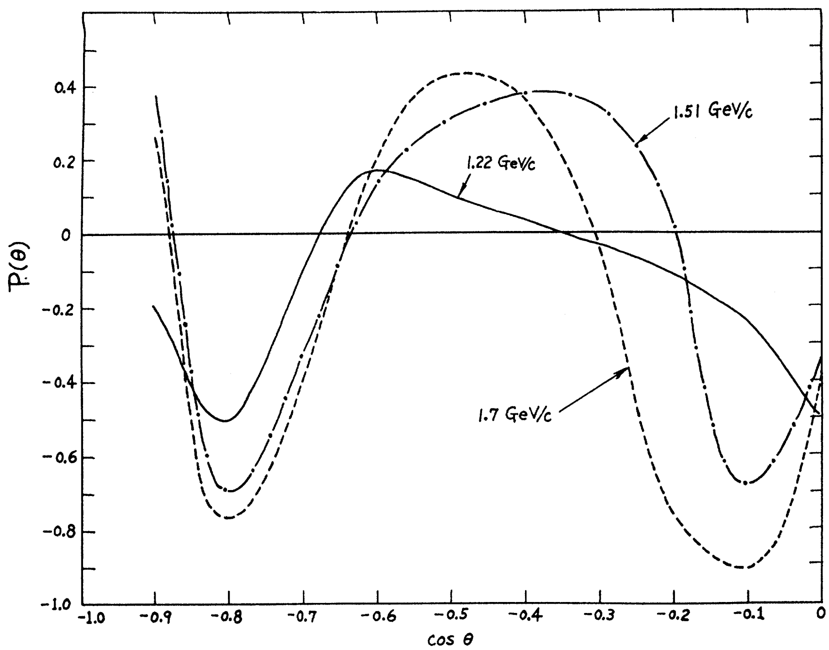

FIG. 7. Theoretical curves for polarization $P(\theta)$ of recoil nucleons in backward K^{-}-p charge-exchange scattering. The solid, dash-dot, and dashed curves show the values of $P(\theta)$ at 1.22, 1.51, and 1.7 GeV/c, respectively.

and opposite sign. This is the reason why we get the results shown in Figs. 6 and 7. In K^{-}-p scattering at 1.5 GeV/c also,[16] the X has the properties similar to those in case of 1.7 GeV/c. The results of our study in this paper[17] enable us to say that important information about the resonant-state Y^*'s, particularly $Y_0^*(2100)$, can be obtained by measurements not only of the differential cross section but also of the polarization of recoil nucleons in *backward* K^{-}-p scattering at 1.5–1.7 GeV/c. Because our spin-parity assignment of the Y^*'s is based on the Regge-recurrence model, it is possible also to evaluate the model by comparing our results with future experiment.

[16] In K^{-}-p scattering at 1.5 GeV/c, the effect of $(R_3^{+*}R_4^{-}-R_4^{-*}R_3^{+})$ is much larger than that of $(R_4^{-*}R_4^{+}-R_4^{+*}R^{-})$.

[17] We have neglected the contributions from the resonant-state Y^*'s whose excitation energies are far from 1–2 GeV/c. This approximation would be fairly good in the description of backward K^{-}-p scattering at 1–2 GeV/c, because the scattering amplitudes due to these resonances would be very small [cf. Eq. (3)]. Even if there are a few resonant states among these Y^*'s whose amplitudes are too large in magnitude to be neglected, some of them contribute with positive sign to the backward-scattering amplitude, others with negative sign, which helps to cancel their effect.

ACKNOWLEDGMENTS

The author would like to express his sincere thanks to Dr. C. G. Wohl, and the authors of Refs. 3 and 6 for kindly sending the results of their work.