likely that the K and the π are associated in some sort of resonant structure; in fact, the Russians seem to have found this at 6.8 Bev.

Thirdly, if you take this picture seriously, it is not easy to account for the large polarization of the Λ^0. Therefore, one should see whether the large Λ^0 polarization remains at these high energies, and if so, I think that this particular interpretation of the angular distributions requires more refinement.

A. M. Wetherell: Yes, I agree with everything you say. With the small hydrogen bubble chamber it was impossible to distinguish between directly produced Λ and Λ coming from Σ^0 decay.

L. Alvarez, *University of California, Berkeley, California:* I have an experimental comment on the remarks just made about the angular distribution of the lambda's. The 30-cm hydrogen chamber has an effective diameter for decay between 10 and 12 cm. That is the potential path. The mean decay distance for a forward produced Λ in this energy range is approximately 200 cm, which makes the effective length of the bubble chamber for this class of events quite small. Have any corrections been made for this? I think the backward peaking is very reasonable, but this instrumental effect introduces a bias.

A. M. Wetherell: Your concern seems valid. Peyrou's group labored at this and they concluded that they should have seen some forward going Λ. This was taken into account.

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K-Nucleon Interaction

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I. INTRODUCTION

THIS paper summarizes the broad details of the K-nucleon interaction and presents data from three new experiments carried out at the Lawrence Radiation Laboratory. These new experiments are: I. the total cross section for K^- mesons on protons and neutrons in the momentum region[1] 1–4 Bev/c; II. total cross section for K^- mesons on protons and neutrons in the momentum region[2] 0.6–1.1 Bev/c; and III. total cross section for K^+ mesons on protons and neutrons in the momentum region[3] 0.8–2.9 Bev/c. In the final section we speculate on some possible interpretations of the data as they appear at the present time. Since the analysis and correction of the data from experiments II and III have not been completed yet, the corresponding results are presented below with rather large errors.

II. K^--NUCLEON TOTAL CROSS SECTION

There are many accurate total cross-section measurements now available for K^- mesons on protons up to a momentum of 10 Bev/c. These data are shown in Figs. 1 and 2. Figure 1 shows the total cross section as a function of laboratory momentum between 1 and 9 Bev/c. The data from experiment I and the data from von Dardel[4] are consistent and indicate that the cross section above 3 Bev/c is essentially flat with momentum at a value of approximately 25 mb. Figure 2 shows the K^- total cross section from 0 to 3 Bev/c. The data from experiment II show a considerable structure (which we tentatively refer to as a "resonance") in the K^--proton cross section in the region of 1 Bev/c. The resonance, however, does not appear—at least to anything like the same degree—in the K^--neutron cross section, also shown in Fig. 2. Since the K^--neutron system is a pure $T=1$ state and the K^--proton system is a mixture of the $T=1$ and $T=0$ states, the resonance in the K^--proton cross section is in the $T=0$ state. The structure evident in the K^--proton cross section in the region 1.5 Bev/c in Figs. 1 and 2 is of smaller magnitude and needs to be investigated more thoroughly. A better idea as to the position and the shape of the resonance at 1 Bev/c can

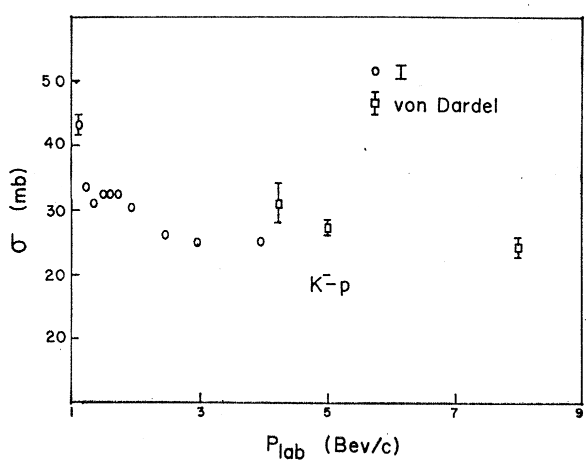

FIG. 1. K^--p total cross section in the momentum range 1–4 Bev/c. For the data of experiment I where no error bars are shown, the errors are smaller than the symbols used.

[1] V. Cook, B. Cork, T. F. Hoang, D. Keefe, L. T. Kerth, W. A. Wenzel, and T. F. Zipf (unpublished).

[2] O. Chamberlain, K. M. Crowe, D. Keefe, L. T. Kerth, A. Lemonick, T. Maung, and T. F. Zipf (to be published).

[3] V. Cook, D. Keefe, L. T. Kerth, P. G. Murphy, W. A. Wenzel, and T. F. Zipf (to be published).

[4] G. von Dardel, D. H. Frisch, R. Mermod, R. H. Milburn, P. A. Piroué, M. Vivargent, G. Weber, and K. Winter, Proc. Ann. Rochester Conf. High Energy Phys. 10, 484 (1960).

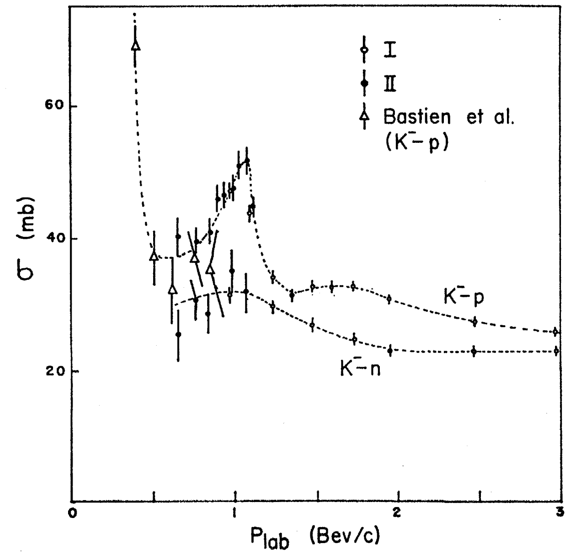

FIG. 2. K^--p and K^--n total cross sections in the momentum range 0–3 Bev/c. The momentum resolution of experiment II was approximately 1%.

be obtained by guessing at the smooth nonresonant background and subtracting it from the data of Fig. 2.

The data in Fig. 3 are plotted as a function of the center-of-mass kinetic energy. The curve is a single level resonance formula drawn for comparison only. No attempt has been made statistically to fit the data. However, it shows that the resonance represents an excess energy in the K^--nucleon system of about 380 Mev and a width of approximately 120 Mev. It has been pointed out[5] that from global symmetry one would expect the same isobaric states that appear in the π-nucleon system to appear in the π-hyperon system. It is interesting to conjecture what such an assumption would predict as far as resonances in the K^--nucleon interaction is concerned. It has been pointed out by Alston *et al.*[6] that the (33) resonance in the π-nucleon system under the foregoing assumption predicts a resonance in the π-hyperon system which corresponds remarkably well to the mass of the Y^*. The Y^* is below threshold in the K^-+p system. However, the other two isobaric states in the π-nucleon system predict isobaric states in the π-hyperon system above the threshold of the K^-+nucleon system. The third π-nucleon isobar would give a resonance in the K^--nucleon system at approximately 275 Mev from an isobar in the $\Lambda\pi$ system, and at about 70 Mev less from the $\Sigma\pi$ isobar. Therefore we would expect two resonances in the K^--nucleon system in the region of 300 Mev in the center of mass. The resonance observed in the K^--p scattering is at slightly higher energy and is somewhat wider than would be expected from the π-nucleon resonance. However, it is impossible to determine from the present data if this is a single resonance or two resonances separated by 70 Mev. The assumption of two overlapping resonances can account for the observed width. There are many difficulties with such an interpretation as this. The fact that the width of the Y^* resonance is now thought to be narrower than the (33) resonance in the π-nucleon system is disturbing. In addition, the idea of global symmetry would predict that the Y^* would have the same spin as the pion-nucleon isobar, i.e., $J=\frac{3}{2}$. At present, it is not clear what is the spin of the Y^* from the experimental data.

The K^--neutron total cross sections from experiments I and II shown in Fig. 2 represent all of the data that is now available. To arrive at K^--neutron cross sections from K^--deuteron scattering is very difficult at low energies. The corrections arising from the spectator proton become unreliable when the proton cross section becomes large—as it does below about 0.6 Bev/c.

III. K^+-NUCLEON TOTAL CROSS SECTION

Figure 4 shows the K^+-proton total cross section as a function of laboratory momentum. In the region between 2 and 3 Bev/c there was some difficulty in drawing a smooth curve through the points of Burrowes *et al.*,[7] at 2.3 Bev/c, and those of von Dardel[4] *et al.*, which start at 3 Bev/c. The new data from experiment III indicates general agreement with all but the highest energy points of Burrowes *et al.* The best description of the K^+-proton total cross section that can be given at the moment is that at zero momentum it starts at about 12 mb (nuclear part only), increases to about 17 mb at about 1.5 Bev/c, and then slowly rises to about 18–19 mb at higher energies. It has been known for some time that at low momenta (below 500 Mev/c) the angular distributions of the K^+-proton scattering indicated that

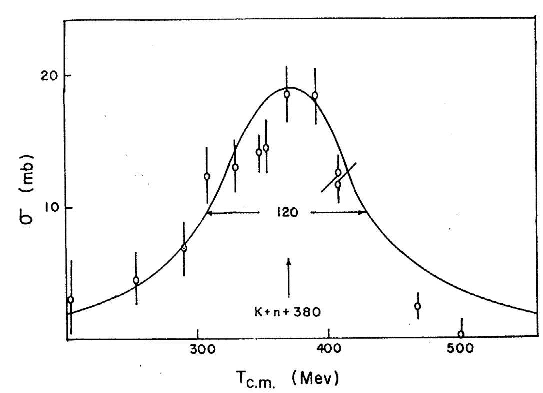

FIG. 3. K^--p total cross section with the nonresonant background subtracted. The curve is a single resonance form drawn for comparison.

[5] D. Amati, M. Fierz, and V. Glaser, Phys. Rev. Letters **4**, 89 (1960); S. F. Tuan, Nuovo cimento **18**, 1301 (1960); A. Pais (private communication); D. Keefe (private communication).

[6] M. Alston, L. W. Alvarez, P. Eberhard, M. L. Good, W. Graziano, H. K. Ticho, and S. Wojcicki, Proc. Ann. Rochester Conf. High Energy Phys. **10**, 445 (1960); Phys. Rev. Letters **5**, 5201 (1960).

[7] H. C. Burrowes, D. O. Caldwell, D. H. Frisch, D. A. Hill, D. M. Ritson, and R. A. Schluter, Phys. Rev. Letters **2**, 117 (1959).

the simplest explanation for the scattering is that of S-wave scattering only. Angular distributions have been taken at as high as 800 Mev/c in a collaborative experiment between the Lawrence Radiation Laboratory and UCLA using the 15 in. hydrogen bubble chamber.[8] They find that at 800 Mev/c the angular distribution is still predominantly S-wave and that the total cross section includes about 1 mb of inelastic scattering. Apart from total cross sections, the angular distributions for elastic scattering at 1.0, 1.2, and 2.0 Bev/c were measured in experiment III. As yet the results are not available; however, it would appear from a preliminary look at the distribution that they are not isotropic, and certainly there is a fair amount of inelastic scattering contributing to the total cross section in this momentum region.

To date there is little data on the K^+-neutron interaction except at lower energies. The K^+-neutron total cross section from emulsion work starts out at a very low value at low momenta and in the region of 500 Mev/c becomes equal to the K^+-proton total cross section and apparently remains equal to it from there to approximately 2 Bev/c. However, the angular distributions indicate that higher angular momentum states play an important role in the elastic scattering. The data from the 15 in. bubble chamber[8] indicate that even at as low as 500 Mev/c it requires D-wave phase shifts to fit the data. Since the K^+-p system is a pure $T=1$ state and the K^+-n system is a mixture of $T=1$ and $T=0$, these states indicate that the $T=0$ state is much more complicated than the $T=1$. The final important point to notice as far as the high-energy behavior of both the K^+- and the K^--proton total cross sections is that each has become flat as a function of energy. However, even at as high as 10 Bev/c they have not become equal. It would seem that for K mesons 10 Bev/c is not a high enough momentum for the Pomeranchuk theorem to obtain.

IV. DISPERSION RELATIONS

At present, the only technique for correlating and parameterizing the strong interaction data which shows any promise at all is that of dispersion relations. Dispersion relations for K-nucleon scattering have been written by analogy to the π-nucleon system.[9] A number of calculations have been carried out in the past using dispersion relations to try to relate the various aspects of the K-proton scattering data.[10] The first thing that one could hope to derive from dispersion relations is the value and sign of the average pole term $\langle pX\rangle_{\text{av}}$ representing the parity and the coupling constant of the K-nucleon-hyperon system. Calculations have been

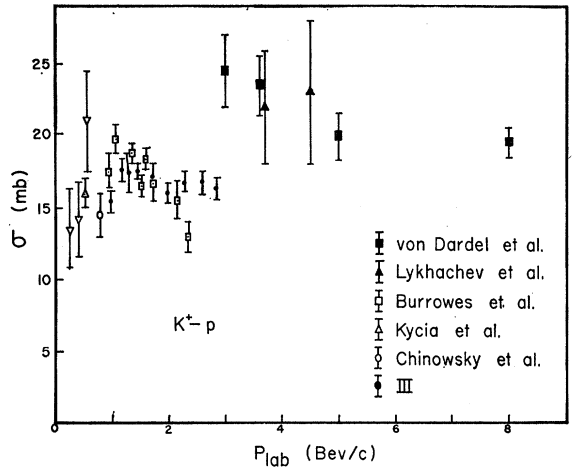

FIG. 4. K^+-p total cross sections in the momentum region 0–8 Bev/c. The data of experiment III is preliminary and is plotted with an error equal to twice the statistical errors.

hampered in the past by the lack of low-energy K^--proton data. Furthermore, the existence of the resonance around 1 Bev/c (Fig. 2), which was heretofore unsuspected, certainly has not been accounted for properly in any of the calculations. The momentum dependence of the total cross section which has been used has usually varied roughly as $1/v$, and consequently the cross sections in the region below 1 Bev/c were overestimated by a large factor. In addition to the lack of total cross section data, there have not been available statistically accurate numbers for the real part of the forward scattering amplitude at various energies. With the new angular distributions which have been measured for both K^+- and K^--proton interactions at various energies and the measurements of the total cross sections at various momenta, it is possible to consider a more reliable use of dispersion relations. In this vein we have calculated the average value of the pole term $\langle pX\rangle_{\text{av}}$ using the doubly subtracted form of the dispersion relation

$$\omega_0 D^+(\omega)-\tfrac{1}{2}(\omega_0+\omega)D^+(\omega_0)-\tfrac{1}{2}(\omega_0-\omega)D^-(\omega_0)$$

after the technique of Karplus, Kerth, and Kycia.[11] On using all of the data presently available, we find a value of the average pole term which varies, depending upon the data used, between approximately -0.1 and -0.4, but small positive values cannot be excluded.

It is believed that with the angular distributions which will be obtained in experiment III, a much better value of the average pole term will be obtained. At the moment it seems premature to report further results on dispersion calculations.

V. SUMMARY

To summarize the present data as far as the K-nucleon interaction is concerned, one may characterize the

[8] G. Goldhaber, W. Chinowsky, S. Goldhaber, W. Lee, T. O'Halloran, T. Stubbs, W. E. Slater, D. H. Stork, and H. K. Ticho (private communication); Proc. Ann. Rochester Conf. High Energy Phys. **10**, 451 (1960).

[9] For a summary see R. H. Dalitz, Proc. Intern. Conf. High Energy Phys. CERN 187 (1958).

[10] P. T. Matthews, Proc. Ann. Rochester Conf. High Energy Phys. **10**, 700 (1960).

[11] R. Karplus, L. T. Kerth, and T. Kycia, Phys. Rev. Letters **2**, 510 (1959).

K^--proton data by a very high cross section at low momentum, varying apparently as approximately $1/v$, with a resonance appearing at about 1 Bev/c, and a final asymptotic value at high energy of about 25 mb. K^--neutron data do not exist at low energies, so the very low energy behavior of the K^--neutron total cross section is not known; however, at higher energies it seems to be approaching the same value as the K^--proton data. Therefore we say that at high energy the $T=1$ and $T=0$ states are approximately equally effective. The resonance appears only in the $T=0$ state and not in $T=1$ state. In the K^+ interaction, the $T=1$ state has a rather simple total cross section behavior rising very slowly at low energies to an asymptotic value of approximately 20 mb at high energies. The $T=0$ total cross section, however, starts at a rather low value at zero momentum, increases to about the same value as in the $T=1$ state in the region of 500 Mev/c, and then remains equal to the $T=1$ state at high energies. On the angular distributions measured in the lower energy K^+-nucleon experiments, one can say that the $T=1$ scattering appears to be predominantly S wave below 800 Mev/c, whereas the $T=0$ state is very much more complicated, requiring up to D waves to fit the data.

DISCUSSION

R. K. Adair, *Brookhaven National Laboratory, Upton, New York:* Concerning the peak in the $K^- - p$ cross section, which you seem reluctant to call a resonance, I think that any time one has a cross section in scattering which increases, it means that the imaginary part also increases. If you apply dispersion theory, in even the most elementary way, this gives a real part of the amplitude which has the characteristic dispersion shape. If you look on a complex (Argand) diagram of the scattering amplitude, it forms a counterclockwise circle. There is no more general definition I know of a resonance, so I think you can call your peak a resonance in perfect safety. As an old neutron scattering worker, I was quite impressed by the shape of this resonance. It seemed to be a very beautiful example of a perfect resonance shape, including the asymmetry and the dip on the backside. It is similar to starting with a 30° positive phase shift and passing through 180°. You reproduce that very beautifully.

If you believe there is a resonance in the $\Lambda\pi$ system, is there not another pole which (according to Mr. Ferro-Luzzi's discussion) has the opposite parity to the Λ? What is its effect?

L. T. Kerth: One must then say that he is determining an average of all these, and that they are no longer very close to the same energy, so that it is not really a very meaningful average.

S. F. Tuan, *Brown University, Providence, Rhode Island:* In your handling of the unphysical region, did you use both the (+) and the (−) Dalitz solutions in estimating the contribution from this region? My impression is that the two cases make substantial differences towards parity determination by dispersion relations, at least for the assumption (Λ,Σ) parity even.

L. T. Kerth: On various integrals I have used both solutions and they make a difference at very low K^- energies, which is expected. It is an interesting thing that small perturbations in the total cross-section curve die out very rapidly in the integrals. As soon as one gets away from them, there is little effect. Actually one gets about the same kind of pole term with either solution. The use of the double subtraction with $\omega_0 \neq 1$ makes the value of $\langle pX \rangle_{av}$ very insensitive to the unphysical region. By taking $\omega_0 \approx 1.2$ where the experiments show[a] $D^-(\omega_0)$ to be very small (of order zero), one finds very little sensitivity to the unphysical region. This conclusion is based on rather poor $K^- - p$ data at low energies.

[a] P. Nordin, Jr. (private communication). This is a re-analysis of the Alvarez 15-in. bubble chamber data presented at the Kiev Conference.