(1974).
[8]D. Bintinger *et al.*, Phys. Rev. Lett. 35, 72 (1975).
[9]V. V. Abramov *et al.*, 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, 1974), p. V-53.
[10]Since single muons at $x_F = 0$ and $P_T > 1$ GeV/c arise almost entirely from parent μ pairs close to $x_F = 0$, the uncertainty in the extrapolation of the pair cross section to $x_F = 0$ also appears directly in these single-muon cross sections.
[11]T. Eichten *et al.*, Nucl. Phys. B44, 333 (1972).
[12]W. F. Baker *et al.*, Phys. Lett. 51B, 303 (1974).
[13]L. B. Leipuner *et al.*, Phys. Rev. Lett. 35, 1613 (1975); H. Kasha *et al.*, Phys. Rev. Lett. 36, 1007 (1976).
[14]D. Buchholz *et al.*, Phys. Rev. Lett. 36, 932 (1976).

Structure in K^--Nucleon Total Cross Sections below 1.1 GeV/c*

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Total cross sections of K^-p and K^-d have been measured between 410 and 1070 MeV/c with high statistical precision. In addition to the well known Λ(1520), Λ(1820), and Σ(1769), we confirmed the presence of the Λ(1692) and the Σ(1670). We have also observed several structures which could be Y^* resonances: Λ(1646), Λ(1735), Σ(1583), Σ(1608), Σ(1633), and Σ(1715).

Meson-nucleon total-cross-section measurements below incident momenta of a few GeV/c have, in the past, provided valuable information on new baryon resonances. A structure in the momentum dependence of the cross section has often been the first indication of a resonance and has also provided a number of its parameters. In addition, such measurements are a very important constraint for phase-shift analyses from which resonances, not directly observable, can be found and have their parameters determined.

The K^--nucleon system in the mass range from 1500 to 1800 MeV is very rich in Y^* resonances; there are claims for about a dozen resonances with status varying from "good, clear and unmistakable" to "weak."[1] Earlier total-cross-section measurements in this region[2-4] cover only limited momentum ranges (giving rise to possible normalization problems between experiments) and do not have the experimental accuracy currently attainable.

The present experiment was part of a series of measurements[5,6] made below 1.1 GeV/c at the Brookhaven National Laboratory alternating gradient synchrotron to give significantly improved data in an interesting momentum region. They were carried out in order to search for new structures and also to provide considerably more accurate data than previously available for phase-shift analyses. Preliminary results of the present data on K^-p and K^-d cross sections have been reported earlier.[7]

The experiment used a standard transmission method with special precautions taken to avoid the problems inherent in such a technique at low momenta; the experimental details and method of data analyses have been given elsewhere.[5,6] In this experiment, the hydrogen and deuterium targets were 3 ft long. Corrections to the data for kaon decay, which could be as large as 20% at low momenta, were verified experimentally at two different momenta by measuring cross sections with varying distances between the target and transmission counters.[5] In evaluating the Coulomb-nuclear interference correction, the slopes of the elastic differential cross sections were obtained from interpolations of the published experimental data.[8,9] The ratios between the real and imaginary parts of the forward-scattering amplitudes for protons were taken from experimental data[10] and were assumed to be the same for neutrons. The kaon momenta were corrected for energy loss in the target. Experimental resolution caused mainly by this energy loss was unfolded from the data by an iterative procedure; the correction was typically about 0.2% and never exceeded 2%.

Statistical errors on the hydrogen cross sections varied from ± 0.23% at high momenta to ± 0.65% at 574 MeV/c and to ± 2.5% at the lowest momentum; the corresponding deuterium percentage errors were about half as much. Rela-

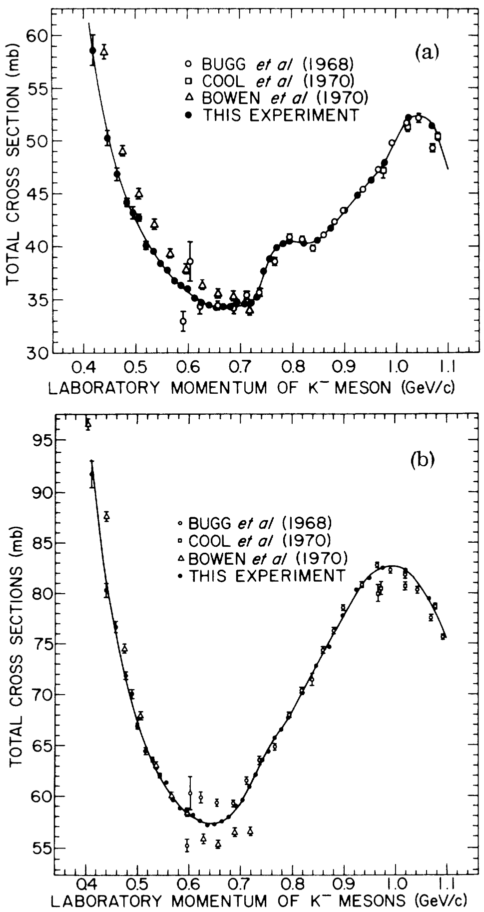

FIG. 1. Results of this experiment for (a) K^-p and (b) K^-d total cross sections, together with existing data (Refs. 2–4). Only statistical errors are shown. Curves are described in text.

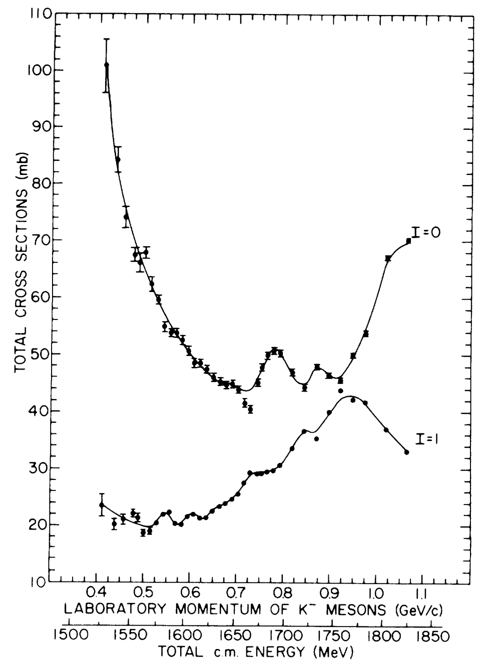

FIG. 2. Total K^--nucleon cross sections for the $I=0$ and $I=1$ isotopic-spin states. The curves are the results of the fits described in the text.

tive point-to-point systematic errors are estimated to be always less than the statistical errors. The overall scale error in the absolute value of the cross section is estimated to be about 1%.

The results of this experiment are shown in Figs. 1(a) and 1(b), together with previous data[2-4] in the same momentum range. The agreement with earlier data is generally good, except for a possible momentum scale shift at low momentum as compared to Bowen *et al.*[4] It can be seen that the statistical accuracy of the present data is considerably improved over the earlier experiments; the number of data points taken is also greater.

The smooth curves in Figs. 1(a) and 1(b) represent the data used in the isotopic-spin analysis and are essentially the same as those obtained from the fits described below. The technique for determining the cross sections in the pure $I=0$ and $I=1$ isotopic-spin states has already been described.[3,11] The parameter $\langle r^{-2}\rangle$ used in obtaining neutron cross sections from those on deuterium and hydrogen was taken[3] to be 0.033 mb^{-1} and assumed to be independent of the kaon momentum.

Figure 2 shows the K^--nucleon total cross sections in the two pure isotopic-spin states. We see a number of structures, many of which have not been observed previously.

We consider the $I=0$ data first. The rise in cross section, as the momentum is reduced towards 400 MeV/c, is due to the nearby well known $\Lambda(1520)$; similarly, the rise towards 1000 MeV/c is due to the $\Lambda(1820)$. We see the previously observed $\Lambda(1692)$, a peak at 1735 MeV, and a smaller one at 1645 MeV. It is possible that there are other structures between 1530 and 1630 MeV.

We have fitted the data with Breit-Wigner forms for the $\Lambda(1520)$ and the $\Lambda(1820)$ with their masses fixed at accepted values,[1] together with a background of the form

$$\sigma_{\text{background}}=A+Bp+C/p,$$

(as indicated by s-wave effective-range theory at low energy). The results of the fit were then subtracted from the data to give an estimate the Breit-Wigner parameters at 1645, 1690, and 1735 MeV. These were then successively combined and refitted with the known structures and the

TABLE I. Results of the fits described in the text. J is the spin and x is the elasticity of a resonance.

Isospin	Laboratory momentum (MeV/c)	Mass (MeV/c^2)	Width (MeV/c^2)	Height (mb)	$(J+1/2)x$
0	685	1646 ± 7	20	1.3	0.04
0	784	1692 ± 4	38	12.4	0.48
0	875	1735 ± 5	28	6.3	0.29
1	546	1583 ± 4	15	2.8	0.06
1	602	1608 ± 5	15	2.4	0.06
1	657	1633 ± 10	10	1.4	0.04
1	737	1670 ± 4	52	6.5	0.23
1	833	1715 ± 10	10	7.0	0.30

background. The results so obtained are given in Table I. The parameters for Λ(1692) are in good agreement with the existing data,[1] while the other two structures, Λ(1646) and Λ(1735), have not been seen before in the total cross sections.

The $I=1$ data were fitted in the same way as for $I=0$. The mass of the well known Σ(1769) was fixed in the fitting procedure; and the same background form mentioned above was used. The smaller structures at 1585, 1610, 1670, and 1715 MeV and a shoulder at 1635 MeV are fitted to yield the parameters given in Table I; there may be other structures below 1560 MeV. Because of the uncertainty of the cross sections below our energy range which would affect the low energy points, the step at about 1550 MeV has been ignored. The existence of the Σ(1583), not previously observed, was noted in a preliminary analysis of this experiment.[7] It has subsequently been observed in an analysis of the reaction $K^-p \to \Lambda\pi$.[12] The other $I=1$ structures, also not observed heretofore in total-cross-section experiments, are in mass regions where there have been claims of resonances, but their number and properties are not clear at present.[1] It is interesting to note that several Y^* resonances in the mass region studied here have been predicted with the use of the quark shell models.[13]

To indicate the significance of the structures discussed above, we note that the Λ(1646) and the Σ(1633) are about three-standard-deviation effects, while all the others are more than five-standard-deviations effects.

In conclusion, we have measured the K^--nucleon total cross sections from 410 to 1070 MeV/c with much improved accuracy over previous experiments. In addition to the well known Λ(1520), Λ(1820), and Σ(1769), we confirmed the presence of the Λ(1692) and the Σ(1670). We have also observed several new structures which could be Y^* resonances: Λ(1646), Λ(1735), Σ(1583), Σ(1608), Σ(1633), and Σ(1715). These data should prove valuable in phase-shift analysis of the K^--nucleon system for an understanding of the rich Y^*-resonance structure in this region.

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[1]V. Chaloupka et al., Phys. Lett. 50B, 1 (1974).

[2]D. V. Bugg, R. S. Gilmore, K. M. Knight, D. C. Salter, G. H. Stafford, E. J. N. Wilson, J. D. Davies, J. D. Dowell, P. M. Hattersley, R. J. Homer, A. W. O'Dell, A. A. Carter, R. J. Tapper, and K. F. Riley, Phys. Rev. 168, 1466 (1968).

[3]R. L. Cool, G. Giacomelli, T. F. Kycia, B. A. Leontic, K. K. Li, A. Lundby, J. Teiger, and C. Wilkin, Phys. Rev. D 1, 1887 (1970).

[4]T. Bowen, P. K. Caldwell, F. Ned Dikman, E. W. Jenkins, R. M. Kalbach, D. V. Petersen, and A. E. Pifer, Phys. Rev. D 2, 2599 (1970).

[5]A. S. Carroll, T. F. Kycia, K. K. Li, D. N. Michael, P. M. Mockett, D. C. Rahm, and R. Rubinstein, Phys. Lett. 45B, 531 (1973).

[6]A. S. Caroll, I-H. Chiang, T. F. Kycia, K. K. Li, P. O. Mazur, D. N. Michael, P. Mockett, D. C. Rahm, and R. Rubinstein, Phys. Rev. Lett. 32, 247 (1974).

[7]K. K. Li, *Baryon Resonances—73* (Purdue University, West Lafayette, Indiana, 1973), p. 283; A. S. Carroll, I-H. Chiang, T. F. Kycia, K. K. Li, P. O. Mazur, D. N. Michael, P. Mockett, D. C. Rahm, and R. Rubinstein, in *Proceedings of the Ninth International Conference on the Physics of Electronic and Atomic Collisions, Seattle, Washington, 1975*, edited by J. S. Risley and R. Geballe (Univ. of Washington Press, Seattle, 1975), p. 376.

[8]B. Conforto, D. M. Harmson, T. Lasinski, R. Levi-Setti, M. Raymund, E. Burkhardt, H. Filthuth, E. Kluge, H. Oberlack, and R. R. Ross, Nucl. Phys. B8, 265

(1968).

[9]R. Armenteros, P. Baillon, C. Bricman, M. Ferro-Luzzi, E. Pagiola, J. O. Petersen, D. E. Plane, N. Schmitz, E. Burkhardt, H. Filthuth, E. Kluge, H. Oberlack, R. R. Ross, S. Barloutaud, P. Granet, J. Meyer, J. P. Porte, and J. Prevost, Nucl. Phys. B21, 15 (1970).

[10]P. Baillon, C. Bricman, M. Ferro-Luzzi, J. M. Perreau, R. D. Tripp, T. Ypsilantis, Y. Declais, and J. Seguinot, Phys. Lett. 50B, 377 (1974); R. D. Tripp, private communication.

[11]R. J. Abrams, R. L. Cool, G. Giacomelli, T. F. Kycia, B. A. Leontic, K. K. Li, and D. N. Michael, Phys. Rev. D 1, 1917 (1970).

[12]P. J. Litchfield, Phys. Lett. 51B, 509 (1974).

[13]R. H. Dalitz, *Baryon Resonances—73* (Purdue University, West Lafayette, Indiana, 1973), p. 393; R. Horgan and R. H. Dalitz, Nucl. Phys. B66, 135 (1973); R. Horgan, Nucl. Phys. B71, 514 (1974).

Reaction ^{3}H(d, n)^{4}He as a Calibrated Polarized Neutron Source and the Analyzing Power of ^{4}He(n, n)^{4}He from 20 to 30 MeV*

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Results are reported for the zero-degree analyzing power and longitudinal vector polarization transfer coefficient values of the reaction ^{3}H(d,n)^{4}He. These data allowed a calibration of the neutron polarization to an absolute accuracy of ± 2%. The analyzing power of ^{4}He was measured using the calibrated neutron beam for E_n in the range 20 to 30 MeV. The results of the ^{4}He analyzing power measurements are compared to phase-shift predictions as well as other data for ^{4}He(n,n)^{4}He and ^{4}He(p,p)^{4}He in the same energy region.

Neutron polarization experiments in the range between 20 and 30 MeV have been handicapped by the lack of a calibrated source of polarized neutrons and by uncertainties in the properties of neutron polarization analyzers. In this brief report we present two sets of results and two types of comparisons which have a significant impact on the solution to these problems. First, the development of the reaction ^{3}H(d, n)^{4}He as a new calibrated source of polarized neutrons is described. Second, the results of a calibration of the only practical neutron polarization analyzer [i.e., ^{4}He(n, n)^{4}He] are given for several angles at energies between 20 and 30 MeV. Next, the latter results for the analyzing power $A_y(\theta)$ are employed to test predictions using four available sets of phase shifts for ^{4}He(n, n)^{4}He. Finally, the values are compared to the $A_y(\theta)$ values for the charge-symmetric process ^{4}He(p, p)^{4}He. The work presented here as a whole should greatly benefit the interpretation of future neutron polarization measurements above 20 MeV.

The calibration of the beam of polarized neutrons was possible because the reaction ^{3}H(d, n)^{4}He possesses specific polarization transfer properties as a result of the $\frac{1}{2}+1\rightarrow\frac{1}{2}+0$ spin structure. In 1971 Ohlsen, Keaton, and Gammel[1] pointed out that in such reactions the zero-degree longitudinal polarization transfer coefficient $K_z^{z'}(0°)$ is simply related to the zero-degree analyzing power $A_{zz}(0°)$. (In this paper the y axis is normal to the reaction plane and the z and z' axes are along $\vec{k}_{in}$ and $\vec{k}_{out}$, respectively.[2] Of course, at the reaction angle of 0° the z and z' axes are collinear.) The relation is given by the equation

$$K_z^{z'}(0°) = \tfrac{2}{3}[1 + \tfrac{1}{2}A_{zz}(0°)], \qquad (1)$$

and the nuetrons emitted at 0° from the $d+{}^3$H reaction have polarization values $p_{z'}$ given by the expression[2]

$$p_{z'} = \frac{\frac{3}{2}K_z^{z'}(0°)p_Z}{1+\frac{1}{2}A_{zz}(0°)p_{ZZ}} = \frac{[1+\frac{1}{2}A_{zz}(0°)]p_Z}{1+\frac{1}{2}A_{zz}(0°)p_{ZZ}}. \qquad (2)$$

Here p_Z and p_{ZZ} are the deuteron vector and tensor polarization components with respect to the polarization symmetry axis which is along $\vec{k}_{in}$.

Experimentally the determination of $A_{zz}(0°)$ is relatively simple, as it involves only a measurement of the ratio of neutron yields for different polarization states of the incident deuteron beam. Hence $A_{zz}(0°)$ may be measured very accurately and used to specify the polarization of the neutron beam emitted at 0°, an angle which provides other unique experimental advantages[3] in neutron polar-