Table I. Groups of strong coupling (SC) and intermediate coupling (IC).

Group of invariance K	Group of SC G	Group of IC Compact	Group of IC Noncompact
SU(2)	SU(2) $\times T_3$	SU(2)$\otimes$SU(2)	SL(2,C)
SU(2)$\otimes$SU(2)	[SU(2)$\otimes$SU(2)] $\times T_9$	SU(4)	SL(4,R)
SU(2)$\otimes$SU(3)	[SU(2)$\otimes$SU(3)] $\times T_{24}$	SU(6)	SL(6,R)
SU(4)	SU(4) $\times T_{15}$	SU(4)$\otimes$SU(4)	SL(4,C)
SU(6)	SU(6) $\times T_{35}$	SU(6)$\otimes$SU(6)	SL(6,C)

but the signs of some structure constants of the original group are irrelevant after the contraction (those structure constants that $\rightarrow 0$). If we choose opposite signs, the original Lie algebra would be noncompact. In other words, it is possible to perform the contraction from a noncompact group. In the previous examples, we could have used SL(2, C) and SL(4, R) instead of SU(2)$\otimes$SU(2) and SU(4), respectively, although the irreducible unitary representations of these noncompact groups are hard to obtain in practice.

The strong coupling limiting process seems to be related to the mathematical concept of contraction. So, it would not be a bad guess that in case of finite coupling constant the relevant group may be a precontracted group, either compact or noncompact, and we may regard it as the "group of intermediate coupling" which presents the higher symmetry of elementary particles. Therefore, it is interesting to know these groups for the more complicated cases. In Table I we give the list of these groups.

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†Associated Midwest Universities—Argonne National Laboratory predoctoral fellow.

[1]C. J. Goebel, Proceedings of the International Conference on High-Energy Physics, Dubna, 1964 (to be published); and Phys. Rev. 138, B1198 (1965).

[2]G. F. Chew and F. E. Low, Phys. Rev. 101, 1570 (1956).

[3]There are solutions of other kinds by extending the algebra further. However, we shall discuss them on another occasion.

[4]E. İnönü and E. P. Wigner, Proc. Natl. Acad. Sci. (U.S.) 39, 510 (1953). See also E. İnönü, Group Theoretical Concepts and Methods in Elementary Particle Physics (Gordon and Breach Publishers, Inc., New York, 1964).

[5]The derivation of relations (I) and (II) that was sketched above was for s-wave mesons. For p waves the same relations hold with the sole difference that in the relation between Δ and $\mathfrak{M}$, $\Delta = 2\mu\mathfrak{M}$, one must replace 2μ by R, where R is the cutoff radius. See reference 1.

[6]C. R. Hagen and A. J. Macfarlane, "Reduction of Representations of SU_{mn} with Respect to the Subgroup $SU_m \otimes SU_n$," Imperial College Report No. ICTP/64/76.

[7]Other interesting representations $(\infty, 1, 0)$ and $(\infty, 1, 1)$ have the following SU(2)$\otimes$SU(2) decomposition: For $(\infty, 1, 0)$ either $(\frac{1}{2}, \frac{1}{2}) + (\frac{3}{2}, \frac{3}{2}) + \cdots + (\frac{1}{2}, \frac{3}{2}) + (\frac{3}{2}, \frac{5}{2}) + \cdots + (\frac{3}{2}, \frac{1}{2}) + (\frac{5}{2}, \frac{3}{2}) + \cdots$, or $(0, 0) + (1, 1) + \cdots + (0, 1) + (1, 2) + \cdots + (1, 0) + (2, 1) + \cdots$; and for $(\infty, 1, 1)$ either $(\frac{1}{2}, \frac{1}{2}) + 2(\frac{3}{2}, \frac{3}{2}) + 2(\frac{5}{2}, \frac{5}{2}) + \cdots + (\frac{1}{2}, \frac{3}{2}) + (\frac{3}{2}, \frac{5}{2}) + \cdots + (\frac{3}{2}, \frac{1}{2}) + (\frac{5}{2}, \frac{3}{2}) + \cdots$, or $(0, 0) + 2(1, 1) + 2(2, 2) + \cdots + (0, 1) + (1, 2) + \cdots + (1, 0) + (2, 1) + \cdots$.

NEUTRON-PROTON CHARGE-EXCHANGE SCATTERING IN THE BeV/c REGION

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Several years ago we measured the n-p elastic charge-exchange cross section at 2.04 and 2.85 BeV.[1] The interesting result from this work was the observation of a sharply peaked angular distribution with a half-width at half-maximum corresponding to a momentum transfer of 150 MeV/c. This is half the width of the pp diffraction peak at these energies. The width of the charge-exchange peak was found to be momentum-transfer invariant and, therefore, the 150-MeV/c width indicates that the difference between the $T = 1$ and $T = 0$ isotopic-spinstate amplitudes has a long tail out to distances of the order of 2 F. That this tail is small can be inferred from a comparison of our measured total charge-exchange cross section[2] of 1.1 mb to the total n-p cross section of 40 mb. There have been a number of attempts[3-6] to fit our results with single π- and ρ-exchange models, but, as yet, no exchange model seems to be completely satisfactory. Recently, calculations have been made which use a single π- and ρ-exchange model with absorption in the initial and final states.[7-9] In all of these papers a secondary peak, due to the spin-flip amplitudes, is predicted at a laboratory angle of about 5°. No such peak appeared in our original data, which extended to $7\frac{1}{2}°$. In this Letter we report the results of a continuation of our previous angular-distribution measurements to a laboratory angle of 15° (momentum transfer 0.78 BeV/c).

The experimental arrangement was substantially the same as in reference 1. The angular-distribution measurements were made at an incident beam momentum of 3 BeV/c. In addition, we measured the zero-degree differential cross section at incident momenta of 1.40, 2.35, and 3.55 BeV/c. The results of the angular-distribution measurements are shown in Fig. 1. Also shown on the same graph are our old data from reference 1, the data of Larsen[10] at 1.37 BeV/c, and those of Manning et al.[11] at 8.15 BeV/c. The zero-degree cross sections have been normalized to each other to facilitate a comparison of the general shape of the curve for each energy. The errors shown are statistical. The data appear to be consistent with a single curve with some slight evidence for a narrowing of the peak at higher energies. In Fig. 2 we replot our experimental data[2] on an absolute cross-section scale (the calibration is described in reference 1) and compare them to the calculations of Henley and Muzinch[7] based on single π and ρ exchange with absorption. All the absorption models[7-9] give approximately the same results. These models are absolute in the sense that the only adjustable parameters, the absorption and coupling constant, have to be chosen so as to fit other experimental data. The absorption is calculated from the pp diffraction scattering[12] and the usual coupling constants, $g_{\rho NN}^2/4\pi \simeq 2$ and $g_{\pi NN}^2/4\pi \simeq 14$, are used. The differential cross section at 0° and the shape of the curve at small angles are predicted quite well, but the rather large secondary maximum is not observed. Single π exchange without absorption has zero cross section at zero momentum transfer, because the $l=0$ partial wave of the spin-independent amplitude just cancels the higher partial waves. The effect of introducing absorption is to remove the lowest partial waves, and this reverses the minimum at

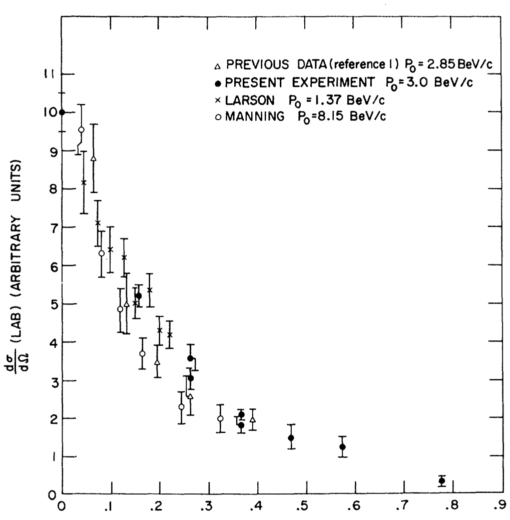

FIG. 1. n-p elastic charge-exchange angular distribution as a function of transverse momentum, $p_\perp = p_0 \sin\theta$. The zero-degree cross sections, for each incoming momentum, have been normalized to the same value. The errors shown are statistical.

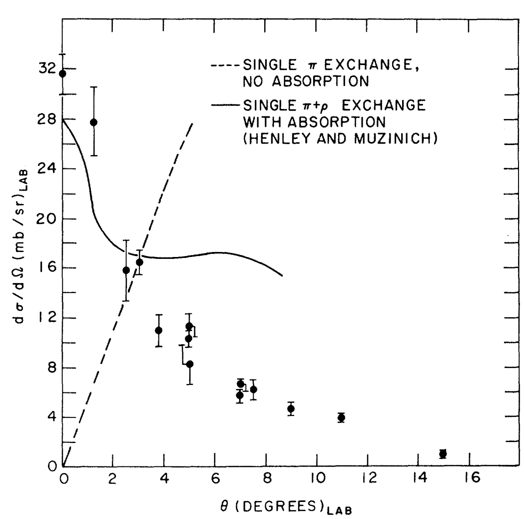

FIG. 2. Measured angular dependence of n-p elastic charge exchange at 3 BeV/c compared to the calculations of Henley and Muzinich based on single π and ρ exchange with absorption. The zero-degree cross section is 31.6±5 mb/sr.

0° into a maximum. On the other hand, all the partial waves of the spin-flip amplitude give zero contribution at $\theta = 0°$. Therefore, absorption has little effect on the shape of the spin-dependent part near zero degrees. On the assumption that the absorption for the direct and spin-flip processes are the same, the resulting total cross section should exhibit the secondary maximum. From the data, it seems that the single-particle-exchange model with absorption accurately predicts the low-momentum-transfer cross section where we are probing only the periphery of the nucleus. However, the model is obviously inadequate for momentum transfers greater than about 150 MeV/c, which corresponds to the rather large interaction distance of 1.3 F.

In Fig. 3 we compare our data with the pp elastic scattering data of Fujii et al.,[13] for $p_\perp > 0.4$ BeV. The straight-line fit is of the form $A\exp(-p_\perp/p_0)$ where p_0 is found to be 0.165 BeV/c. This is to be compared to the value of 0.15 BeV/c used by Orear[14] to fit the high-energy, large-momentum-transfer pp-scattering data. Even though we are still in what might be called the low-momentum-transfer region, there is some indication that the slope of the n-p charge exchange distribution is approaching that of the pp data. This would support Wu and Yang's[15] statistical hypothesis regarding elastic nuclear scattering, wherein, at large $p_\perp$, the cross section is determined by the probability of accelerating the various parts of a nucleon without its breaking up. Therefore, the dependence of the cross section on $p_\perp$ should be the same regardless of the mechanism leading to the formation of the "excited nucleon." Wu and Yang further speculate (independent of the assumptions that lead to the $p_\perp$ dependence) that if the elastic differential cross section in the various isotopic-spin channels have, on the average, the same absolute amplitudes with random relative phases, then we should find that

$$\frac{d\sigma}{d\Omega}(\theta, pp\to pp)\Big/\frac{d\sigma}{d\Omega}(\pi-\theta, pn\to pn) = 2.$$

The observed ratio of 10 leads one to believe that nucleon reactions in the momentum transfer region, $0.5 \le p_\perp \le 1.1$ BeV/c, are not completely dominated by the statistical nature of the process.

Figure 4 shows the same data on a t plot, where t is the negative square of the Lorentz-invariant four-momentum transfer. The line is a two-exponential fit, $d\sigma/dt = 6.9e^{49t} + 4.1e^{4.0t}$. In the low $-t$ region, the slope

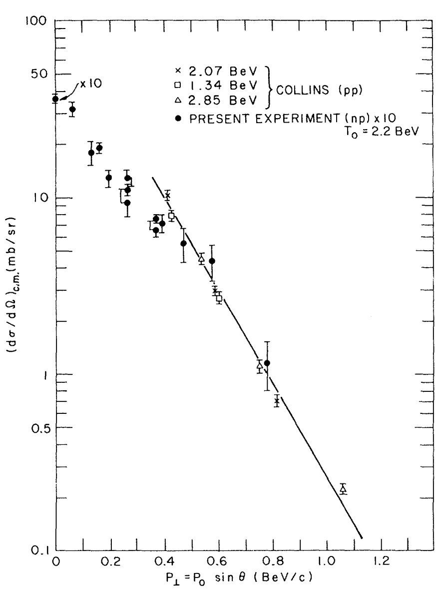

FIG. 3. A comparison of the large-momentum-transfer n-p charge-exchange cross section with the pp cross section. Note that our data have been multiplied by a factor of 10. The slope of the straight line, 0.165 BeV/c, is almost the same as that used by Orear (0.15 BeV/c) to fit the high-energy, large-$p_\perp$, pp data.

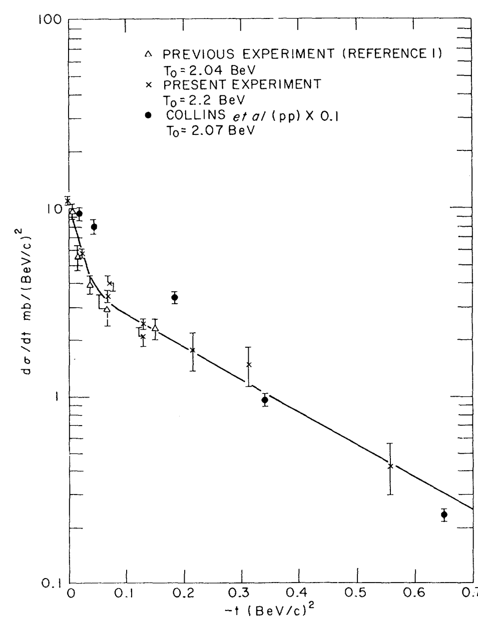

FIG. 4. A two-exponential fit to the np charge-exchange angular distribution. $d\sigma/dt$ [mb/(BeV/c)^2] $= 6.9e^{49t} + 4.1e^{4.0t}$.

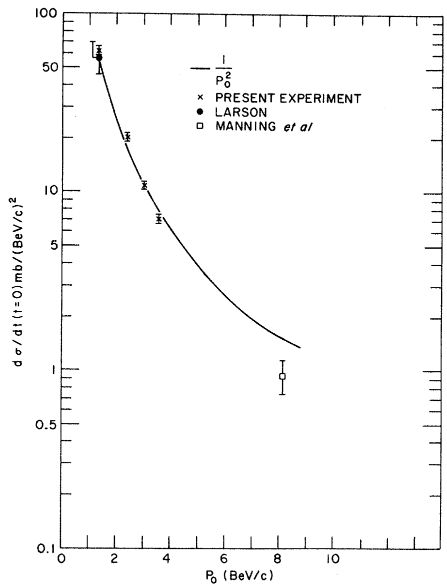

FIG. 5. Momentum dependence of the $t=0$ np charge-exchange cross section between 1.4 and 8.15 BeV/c.

α is much greater than for either pp scattering ($\alpha=6.6$) or $\bar{p}p$ scattering ($\alpha\simeq 15$). Manning and co-workers[16] have recently completed their large-momentum-transfer measurements ($-t > 0.1$) with the preliminary result that the slope in this region increases as the incident momentum increases, similar in manner to the pp data.

In Fig. 5 we plot the $t=0$ absolute cross section as a function of incident momentum. Our errors (~5%) are due almost entirely to the flux calibration at each energy. An additional 10-15% has to be added for other systematic errors discussed in reference 1. However, these errors are not momentum dependent and were not included for this comparison. The error on Manning's point is only preliminary while that for Larsen includes systematic and statistical errors. The $t=0$ cross section decreases with an approximate $1/p_0^{\,2}$ dependence. In contrast, the pp cross section at $t=0$ does not vary appreciably with p_0.

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[2]The zero-degree laboratory cross section quoted in reference 1 was slightly in error. The correct value is 31.6±5 mb/sr. As determined in the present experiment, the large-angle extrapolation of the differential cross section used in reference 1 to obtain the total cross section was too low. Using the new data we obtain a total charge-exchange cross section of 1.1±.25 mb.

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