measurable V^0's as γ's, in the ratio of γ's over total V^0's. This yielded the total of 154 events quoted in Table I.

[5]G. Charlton *et al.*, ANL Report No. AN/HEP 7245, 1972 (to be published).

[6]T. M. Knasel, DESY Reports No. 70/2 and No. 70/3, 1970 (unpublished). The pair-production cross section drops from its asymptotic value by a factor ≥ 2 for photon momenta below 100 MeV/c. We have, therefore, eliminated three events having less than 100 MeV/c lab momentum. We have corrected for this by doubling the weight factors of those events which, on the Peyrou plot, fall under the reflection (about zero c.m. longitudinal momentum) of the curve corresponding to $P_{1\text{ab}} = 100$ MeV/c. This minimum lab-momentum cut excludes a negligibly small area near the origin of the Peyrou plot, bounded by $P_\perp \leq 10$ MeV/c and $0 \leq P_L \leq 5$ MeV/c.

[7]M. Fidecaro *et al.*, Nuovo Cimento 24, 73 (1962).

[8]The turnover of $2P_\perp F_2$ at small $P_\perp$ (< 0.05 GeV/c) is expected for finite F_2. Results at 12.4 GeV/c show a sharp decrease for $P_\perp < 0.1$ GeV/c; see J. H. Campbell *et al.*, in Proceedings of the Sixteenth International Conference on High Energy Physics, National Accelerator Laboratory, Batavia, Illinois, 1972 (to be published).

[9]Evidence in support of this assumption is discussed by G. R. Charlton and G. H. Thomas, Phys. Lett. 40B, 378 (1972); and by S. N. Ganguli and P. K. Malhotra, Phys. Lett. 39B, 632 (1972).

[10]If the distributions in $P_\perp^2$ for π^- and π^0 are similar, one overestimates $\langle P_\perp(\pi^0)\rangle$ by a few percent using $2 \times \langle P_\perp(\gamma)\rangle$. An exact relation, $\langle P_\perp(\pi^0)^2\rangle = 3\langle P_\perp(\gamma)^2\rangle - \frac{1}{2}m_{\pi^0}^2$ [G. I. Kopylov, Phys. Lett. 41B, 371 (1972)], gives $\langle P_\perp(\pi^0)^2\rangle = 0.22 \pm 0.04$.

[11]H. Bøggild *et al.*, Nucl. Phys. B27, 285 (1971).

[12]See, for example, H. J. Lipkin and M. Peshkin, Phys. Rev. Lett. 28, 862 (1972).

[13]G. Flügge *et al.*, in Proceedings of the Sixteenth International Conference on High Energy Physics, National Accelerator Laboratory, Batavia, Illinois (to be published).

[14]J. W. Elbert *et al.*, Nucl. Phys. B19, 85 (1970), discuss $\langle\pi^0\rangle$ in $\pi^- p$ interactions. See also Bucharest-Budapest-Cracow-Dubna-Hanoi-Serpukhov-Sofia-Tashkent-Tbilisi-Ulan Bator-Warsaw Collaboration Report "P," No. 1411/VI/Ph, 1972 (to be published); $\langle\pi^0\rangle$ in pp collisions has been discussed by H. Bøggild *et al.*, Ref. 11. For a comparison between data and a number of current models of high-energy multiplicities, see E. L. Berger, D. Horn, and G. H. Thomas, ANL Report No. ANL/HEP 7240, 1972 (unpublished).

Role of π in High-Energy n-p Charge Exchange

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The forward peak in n-p charge-exchange reactions is accounted for by a simple Born model. The value of the peak is shown to be due to u-channel π^0 exchange, whereas its shape is found to be determined by the interference between the above mentioned π^0 contribution and a π^+ exchange in the t channel. The agreement with the data is fairly good for all incident momenta above 3 GeV/c and for a range of momentum transfer $0 < |t| < 0.005$ (GeV/c)^2.

Forward-direction n-p charge-exchange scattering exhibits a narrow peak[1] characteristic of t-channel pion exchange, i.e., a peak whose width is about m_π^2. One-pion exchange (OPE) calculations in the Born model yield, however, a vanishing contribution in the forward direction. Possible elimination of this disagreement is offered by an absorptive modification of the OPE Born amplitude.[2] Phillips[3] has accounted for the forward peak by a different, though not completely unrelated, method, namely, by the addition of a slowly varying background which interferes destructively with the OPE amplitude. The absorptive corrections as well as Phillips's background term are treated phenomenologically and fitted to the data. Muzinich[4] attempted to explain the data by a single Reggeized ρ exchange whose parameters were *fitted* to the data. Phillips in a further publication[5] showed that such a model cannot fit all the data and must, moreover, possess a rapidly varying residue function.

Islam and Preist[6] suggested a Born model in which the ρ *and* π are exchanged *both* in the t *and* the u channel. Their ρ is coupled only electrically to the nucleon, and the fitted coupling constant is smaller than the commonly accepted value. This is probably due to the non-Reggeized treatment of the ρ. The sharp forward peak is obtained by assigning a steep form factor to the ρ-nucleon vertex. Another strange feature of Ref. 6 is curve b in Fig. 2 which shows a very low pion contribution in the forward direction in contrast to our following result of the *same* calculation. A modification of the lower partial waves of the OPE amplitude is also responsible for the success of Byers's[7] calculation of the forward peak. It is this modification which replaces the troublesome factor t in the amplitude by m_π^2 [see Eqs. (1) and (19), and footnote 9 in Ref. 7], thereby eliminating the forward dip. The same substitution, i.e., replacement of the troublesome t by m_π^2, is essentially also the content of Williams's[8] procedure of eliminating Kronecker δ's in the partial-wave expansion. These replacements in the OPE amplitude, however, look rather *ad hoc*, and a more natural explanation of the forward peak seems desirable.

Recalling the success of Richter's explanation[9,10] of the forward peak in charged-pion photoproduction, one is tempted to look for a similar explanation in n-p charge exchange, i.e., one takes, in addition to the π^+ exchange in the t channel, the π^0 exchange in the u channel and looks for the effect of the interference term. The corresponding scattering amplitude is given by

$$T=(2\pi)^{-6}g^2\left[\frac{2}{t-m_\pi^2}\bar{u}(p_p')\gamma_5u(p_n)\cdot\bar{u}(p_n')\gamma_5u(p_p)+\frac{1}{u-m_\pi^2}\bar{u}(p_n')\gamma_5u(p_n)\cdot\bar{u}(p_p')\gamma_5u(p_p)\right], \tag{1}$$

where p_p and p_n are the momenta of the ingoing proton and neutron, respectively, and p_p' and p_n' the corresponding outgoing momenta. The momentum transfer t is defined by $t\equiv(p_p'-p_n)^2$ and $u\equiv(p_n'-p_n)^2$. The pion-nucleon coupling constant g is taken to be $g^2/4\pi=14.7$.

Performing the trace calculations one obtains for the unpolarized cross section at $s\gg m_N^2$

$$\frac{d\sigma_T}{dt}\approx\left(\frac{g^2}{4\pi}\right)^2\frac{\pi}{s^2}\frac{3t^2+m_\pi^4}{(t-m_\pi^2)^2}. \tag{2}$$

The right-hand side of this equation consists, in fact, of three contributions, i.e.,

$$\frac{3t^2+m_\pi^4}{(t-m_\pi^2)^2}=\frac{4t^2}{(t-m_\pi^2)^2}+1-\frac{2t}{t-m_\pi^2}. \tag{3}$$

The first term on the right-hand side of (3) is due to π^+ exchange in the t channel, the second term is due to π^0 exchange in the u channel, while the last term is due to the interference of these two contributions. Equation (2) is expected to describe the data only for a small range of $|t|$ up to $|t|\approx m_\pi^2=0.02$ (GeV/c)^2. More precisely let us note that $d\sigma_T/dt$ rapidly decreases from its value at $t=0$ to $\frac{3}{4}$ of this value at $|t|=m_\pi^2/3\approx0.007$ (GeV/c)^2 where it reaches its minimal value. For $|t|>m_\pi^2/3$, $d\sigma_T/dt$ again increases with $|t|$ in contrast to the decreasing behavior of the experimental cross section $d\sigma_E/dt$. Equation (2) can therefore be expected to hold only for $0<|t|<0.007$ (GeV/c)^2. We shall now show that in this range of $|t|$ Eq. (2) indeed accounts for the observed experimental data.

Consider first the energy dependence of $d\sigma_E/dt$. It was shown by Miller *et al.*[1] (see their Fig. 2) that for incident momenta p in the range $3<p<11.75$ (GeV/c), $d\sigma_E/dt=A(t)p^{-n(t)}$ with $n(t)\approx2$ for $0<|t|<m_\pi^2/3$. This energy behavior continues to hold also for the higher incident momenta of Engler *et al.*[1] and is in full agreement[11] with the s^{-2} behavior of $d\sigma_T/dt$. Thus, we need to compare $d\sigma_T/dt$ with $d\sigma_E/dt$ at only *one* value of p which we arbitrarily choose to be $p=8$ GeV/c. A convenient way to undertake this comparison is to form the ratio

$$R(t)=\frac{d\sigma_E/dt}{d\sigma_T/dt}.$$

It turns out that for the data of Engler *et al.*[1] which is given numerically (see their Table I), this ratio is *constant*, within experimental error, in the range $0<|t|<0.005$ (GeV/c)^2. Unfortunately, the ratio is *not* 1 but 1.9. However, it has been noted in Ref. 1 that the data may contain a systematic error factor of 2. In fact, the data of Manning *et al.*[12] have the same shape as the data in Ref. 1, but are reduced by a factor of 2.5. In other words, for Manning's data $R(t)\approx0.8$ in the range $0<|t|<0.005$ (GeV/c)^2. Let us also remark that a similar discrepancy of a factor of ~2 between experiment and the Born amplitude also exists in charged-pion photoproduction (Fig. 2 of Ref. 10). The important point to note, however, is that the *shape* as well as the *order of magnitude* of the forward peak are correctly given by the Born amplitude in *both* cases.

It is worthwhile to add at this point a somewhat speculative remark. It is well known that, in order to quench the relatively strong increase of $d\sigma_T/dt$ beyond $|t|=0.007$ (GeV/c)^2, some sort of absorptive corrections should be applied. It could happen that as a result of the two competing trends, i.e., quenching effect versus increasing Born amplitude, there might remain somewhere at $|t|>0.007$ (GeV/c)^2 a residual shoulder or maximum. This might be related to the weak shoulder at $|t|=0.04$ (GeV/c)^2 noted by Miller *et al.*[1] Let us now turn to polarization effects. It is easy to check that Eq. (1) yields zero polarization. This is in fair agreement with the data[13] for $0<|t|<0.005$ (GeV/c)^2.

Finally, it is interesting to observe that in our model the *value* of the forward peak is provided for by the second (constant) "background" term in Eq. (3) due to u-channel exchange, whereas the strong decrease with $|t|$ is provided for by the last term in (3), i.e., by the destructive interference between the background term and the t-channel term. The t-channel term itself [i.e., the first term on the right-hand side of Eq. (3)] has little influence on the $|t|$ dependence of the forward peak. This brings us back to the model suggested by Phillips[3] where we now possess a natural explanation for the background term and for its *destructive* interference with the OPE amplitude.

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Lepton Symmetry

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Assuming a weak interaction invariant under $SU(2)_M\otimes SU(2)_I$, we show that M-spin conservation leads to the rule $A(\nu_e e^-|\nu_e e^-)-A(\nu_\mu e^-|\nu_\mu e^-)=A(\nu_e\mu^-|\nu_\mu e^-)$ and to other sum rules for leptonic, semileptonic, and trident production processes. The additional assumption of total isospin conservation yields simple relations for lepton-hadron scattering. We also show that μ decay is forbidden in lowest order for various symmetry schemes such as the SU(3) and O(3) theories based upon the Konopinski-Mahmoud assignment of lepton number.

Lepton symmetries based upon the observed spectrum of leptons lead to simple relations among leptonic and semileptonic processes that are becoming amenable to experimental observation. We consider the consequences of assuming lepton-number conservation, a $V-A$ form for the four-fermion interaction, and an invariance under an $SU(2)_M\otimes SU(2)_I$ symmetry. M spin describes the μ content of a system of leptons, and I is the weak isospin[1]; the classification of the known leptons is given in Table I. The $SU(2)_M\otimes SU(2)_I$ symmetry is of interest both for its di-

TABLE I. Lepton quantum numbers.

Lepton	M_z	I_z	Lepton No.
ν_e	1/2	1/2	1
e^-	1/2	−1/2	1
ν_μ	−1/2	1/2	1
μ^-	−1/2	−1/2	1
$\bar{\nu}_e$	−1/2	−1/2	−1
e^+	−1/2	1/2	−1
$\bar{\nu}_\mu$	1/2	−1/2	−1
μ^+	1/2	1/2	−1