It is hoped that this analysis will help in a better understanding of the fundamental nature of the pion-nucleon interaction. Further studies using more realistic well shapes and including absorption are in progress.

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PION-PROTON ELASTIC SCATTERING AT 2.00 GeV/c†

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In the course of a spark chamber experiment which studied pion-proton elastic scattering up to 5 GeV/c,[1,2] we measured the π^-p elastic differential cross section at 2.01 GeV/c with high statistical accuracy (7000 elastic events) and the π^+p elastic differential cross section at 2.02 GeV/c with moderate statistical accuracy (1400 elastic events). This momentum is of particular interest, as a resonance has recently been found in the π^-p total cross section at 2.08 GeV/c by Longo and Moyer[3] and by Diddens et al.[4] Diddens et al. also found a resonance at 2.51 GeV/c in the π^+p total cross section, so that 2.0 GeV/c lies midway between this new π^+p resonance and the previously known π^+p resonance[5] at 1.5 GeV/c. The data presented below show that there is a second maximum in the π^-p differential cross section at $\cos\theta = 0.2$ (in the barycentric system). This second maximum is less pronounced in the π^+p system. It is also shown that while the width of the π^+p diffraction peak changes considerably in the 1.0 to 3.0 GeV/c momentum interval, no significant change in the width of the π^-p diffraction peak is observed in this interval.

The differential cross sections are plotted in a semilogarithmic form in Figs. 1 and 2. The errors are statistical and do not include an over-all normalization error of $\pm 8\%$ for π^-p and $+20\%$, -10% for π^+p. The total elastic cross sections are 7.94 ± 0.9 mb for π^-p and $9.1^{+2}_{-1.3}$ mb for π^+p.

The second maximum which appears in the π^-p differential cross section, Fig. 1, is not seen at 3.0 GeV/c or above,[1,2] or at 1.6 GeV/c[6]

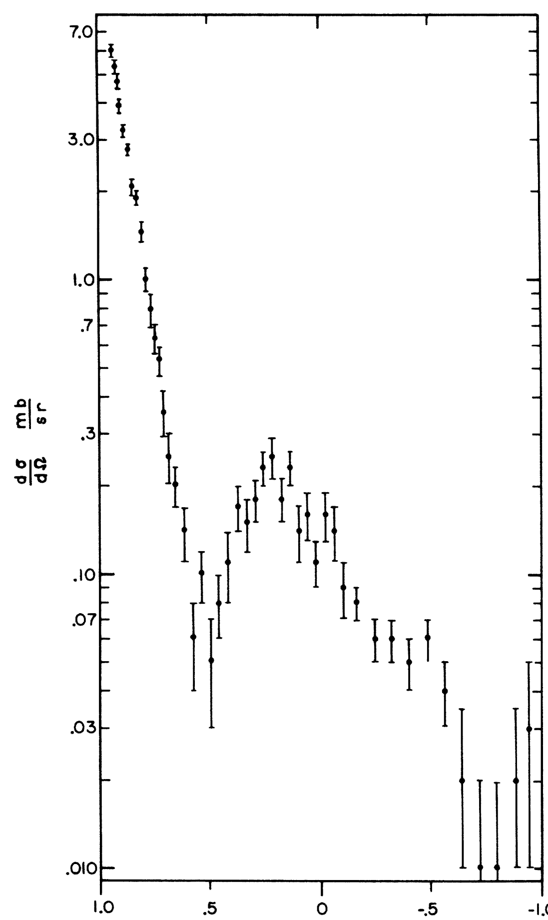

FIG. 1. Differential cross sections in the barycentric system for π^-p elastic scattering. The errors are statistical and do not include an over-all normalization error of $\pm 8\%$.

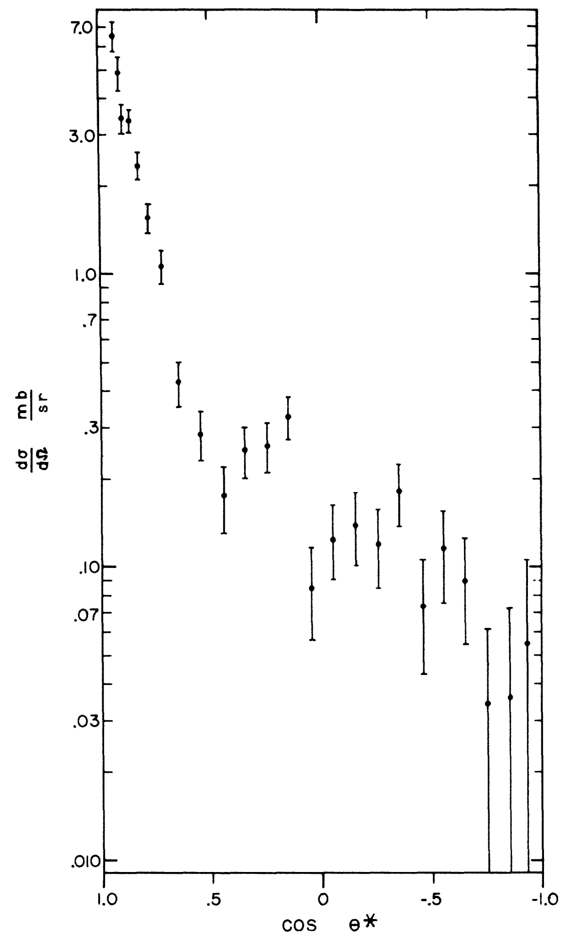

FIG. 2. Differential cross section in the barycentric system for π^+p elastic scattering. The errors are statistical and do not include an over-all normalization error of +10%, -20%.

or below.[7-11] Unfortunately, other measurements at 2.5[8] and 2.8[12] GeV/c have insufficient accuracy to observe this second maximum. However, an unpublished differential cross-section measurement at about 1.85 GeV/c by Erwin and Walker[13] gives some evidence for this second maximum.

The interpretation of this second maximum as simply the second maximum in a diffraction pattern meets with several difficulties. First, if such a diffraction effect exists, one would expect it to be seen over a very large range of energies. Second, one cannot simultaneously fit the width of the first diffraction peak and the position of the second peak. If one adjusts the interaction radius to fit the position of the second maximum, it is then about 30% smaller than one would obtain by fitting the width of the main diffraction peak. Third, the model predicts additional peaks which are not seen. These would, however, probably disappear with the use of a more realistic model, e.g., one with a slightly diffuse boundary.

The π^+p differential cross section confirms the previous measurement and conclusions of Cook et al.[14] that the π^+p differential cross section is larger than the π^-p for all regions outside the diffraction peak at 2.0 GeV/c. Cook et al. and Helland et al.[9] showed that in the momentum region of the 1.5-GeV/c π^+p resonance, there is a large bump in the π^+p differential cross section in the backward hemisphere of the barycentric system. The comparatively larger size of the π^+p differential cross section outside the diffraction peak at 2.0 GeV/c may be the remains of this bump and therefore related to the 1.5-GeV/c resonance. As seen in Fig. 2, in the π^+p system there is evidence for a second maximum at $\cos\theta = 0.2$ rising out of this background, but it is considerably less pronounced than in the π^-p case. Therefore our tentative conclusion on the basis of existing data is that the second maximum at $\cos\theta = 0.2$ is the strongest in the π^-p system and is related to the 2.08-GeV/c π^-p total cross-section resonance.

As another way to look for relations between the peak in the total cross section and the shape of the elastic differential cross section, we have made use of the diffraction peak parametrization used at higher energies:

$$d\sigma(\theta)/d\Omega = [d\sigma(\theta)/d\Omega]_0 e^{At}, \tag{1}$$

where $d\sigma(\theta)/d\Omega$ is the differential cross section in the barycentric system in mb/sr, and t is the square of the four-momentum transfer in (GeV/$c)^2$. In this momentum range, and with measurements of high statistical accuracy, this simple exponential is not a very good fit, but it is a very useful way to measure the width of the diffraction peak, because the peaks are roughly exponential out to $t = 0.4$ (GeV/$c)^2$. In Table I we have listed the values of A obtained by a least-squares fit to this and other experiments for the interval $0.0 \leq t \leq 0.4$ (GeV/$c)^2$. $P(\chi^2)$, the probability of obtaining a χ^2 as large as given by the fit, is also listed. For comparison, it should be noted[2] that at momenta above 3 GeV/c the A's of the $\pi^\pm p$ diffraction peaks have a constant value of 7.6 to 7.9 (GeV/$c)^{-2}$. Table I

Table I. Exponential fits to diffraction peaks.

Incident pion laboratory momentum (GeV/c)	A (GeV/c)^2	$P(\chi^2)$	Reference
	π^-p elastic scattering		
1.34	7.5 ± 0.4	0.40	a
1.48	7.5 ± 0.4	0.20	b, c
1.59	7.1 ± 0.2	0.01	d
1.85	9.3 ± 1.7	0.30	e
2.01	7.8 ± 0.2	0.50	This experiment
2.5	8.5 ± 0.8	0.20	c
3.15	7.9 ± 0.3	0.02	f
	π^+p elastic scattering		
1.12	4.1 ± 0.2	0.25	g
1.45	7.4 ± 0.6	0.30	g
1.50	8.2 ± 0.3	0.15	h
1.69	6.4 ± 0.2	0.02	g
2.00	5.0 ± 0.4	0.70	h
2.02	5.7 ± 0.4	0.40	This experiment
2.50	6.9 ± 0.5	0.02	h
2.92	7.6 ± 0.3	0.20	f

[a]See reference 10.
[b]See reference 7.
[c]See reference 8.
[d]See reference 6.
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[f]See reference 1.
[g]See reference 9.
[h]See reference 14.

shows that for the π^-p system the A values rise rather smoothly from 7.0 (GeV/c)$^{-2}$ at 1.34 GeV/c to 7.9 (GeV/c)$^{-2}$ at 3.15 GeV/c. That is, the π^-p diffraction peak simply narrows slightly over this momentum range. On the other hand, the A values of the π^+p system increase from 4.0 (GeV/c)$^{-2}$ at 1.12 GeV/c to a peak of about 8.2 (GeV/c)$^{-2}$ at 1.5 GeV/c, then decrease to 5.0 (GeV/c)$^{-2}$ and finally rise again at 2.92 GeV/c to 7.6 (GeV/c)$^{-2}$ which is close to the π^-p value at that momentum. This behavior can be thought of as a considerable narrowing of the diffraction peak over the 1- to 3-GeV/c interval combined with a sudden and temporary narrowing at 1.5 GeV/c, possibly associated with the resonance at that momentum.

Finally, we point out that the high statistics in the π^-p data make evident some structure in the diffraction peak. In particular, the $0.0 \leq t \leq 0.2$ (GeV/c)^2 interval has a steeper slope than the $0.0 \leq t \leq 0.4$ interval, 9.6 ± 0.9 as compared to 7.8 ± 0.2 (GeV/c)$^{-2}$. That is, on the semilogarithmic plot there is a definite concave upward slope to the diffraction peak.

We would like to suggest that the detailed structure and energy dependence of the elastic diffraction peak parameters might prove to be a useful approach to studying properties of resonances at higher energies where the interaction is mostly inelastic.

Thus it would be particularly interesting to compare accurate π^-p diffraction data at several energies about the 2.08-GeV/c resonance to see if the diffraction peak has structure at this point analagous to the narrowing of the π^+p diffraction peak at the 1.5-GeV/c resonance.

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EXPERIMENTAL STUDY OF THE CASCADE TIME OF NEGATIVE MESONS IN A LIQUID HELIUM BUBBLE CHAMBER*

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We wish to report preliminary results of a measurement of the cascade time of π^- mesons in liquid helium, and to discuss some possible implications of the result. We mean by cascade time the period between initial atomic capture of the meson and its absorption by the nucleus. It is important to understand the mechanism of the cascade since it determines not only the cascade time, but other important effects such as the angular momentum states from which mesons are absorbed by the nucleus.

If channel k is one of r channels through which the meson cascades in average time T_k from initial atomic capture to nuclear absorption, and if N_k is the number of mesons cascading through channel k, then we define the average cascade time to be

$$T=\left(\sum_{k=1}^{r}N_kT_k\right)\Big/\left(\sum_{k=1}^{r}N_k\right).$$

This is equivalent to

$$T=\tau_d(N_d/N_s),$$

where τ_d is the mean life against decay of the meson, N_d is the number of mesons observed to decay at rest, from a total sample, N_s, of mesons observed to stop in liquid helium.

The technique used to determine the cascade time, T_π, is exactly the same as that used by Fields et al.[1] in liquid hydrogen. In the present case, π^- mesons were stopped in a 1.3-liter liquid helium bubble chamber,[2] and the range and angle of all backward π-μ decays were measured to determine the velocity of the pion at the instant of decay. We observe 11 decays at rest with $\theta_{\pi\mu} > \frac{1}{2}\pi$ for a sample of 2255 π^- stops in the chamber. Because of range straggling, we cannot distinguish pions slower than $\beta_\pi \approx 0.01$ from stopped pions; however, the time taken by the pion to go from $\beta_\pi = 0.01$ to atomic capture has been estimated[3] to be much shorter than the cascade time measured here. From ordinary stopping power theory we calculate that the number of events between $E_\pi = 0.175$ MeV and $E_\pi = 1$ MeV with $\theta_{\pi\mu} > \frac{1}{2}\pi$ should be 0.8. We observe none. From the observed number of backward decays at rest we calculate the cascade time to be

$$T_\pi=[2N_d(\theta_{\pi\mu}>\tfrac{1}{2}\pi)/N_s]\tau_d=(2.5\pm1.0)\times10^{-10}\text{ sec}.$$

Day[4] has made theoretical estimates of the magnitudes of several effects which might be of importance in determining the history of a typical K^- meson during its cascade. Day assumes that the meson is initially captured from the continuum into a bound orbit with principal quantum number $n \approx 30$, ejecting one of the atom's electrons in the process. Because of the strong binding of electrons in helium, the $(K^- \text{He}^{++})$ ion cannot capture electrons from neighboring atoms, and therefore only one ordinary Auger transition of the K^- meson is possible. In addition to ordinary radiative transitions, Day considers three other mecha-