ordinate system for the 100-kev and 50-kev (unpolarized molecular ions) particles are negligible when compared with the resolving power of the neutron detectors.

The current of the polarized beam can be calculated from a knowledge of counting rates, total ion current, partial pressure of deuterium admitted for the unpolarized ions, and the geometry of the electron gun. The current so calculated is 0.01 μa. Typical neutron counting rates are as follows: atomic beam ionized, 700 min^{-1}; residual gas ionized with normal gas admission but no atomic beam, 170 min^{-1}; residual gas ionized without gas admission, 130 min^{-1}; no ionization but accelerating voltage present, 50 min^{-1}.

Investigations of the residual gas ions show the source in its present form is unsuitable for the generation of polarized protons, since about 5 times as many protons originate in the residual gas as in the atomic beam. This is attributed for the most part to the use of rubber seals and oil diffusion pumps; furthermore, no special care has been taken to reduce the residual gas pressure.

[1]A detailed description of the source with an extensive bibliography will soon appear in Helvetica Physica Acta.

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NEGATIVE PION-PROTON ELASTIC SCATTERING AT 600 TO 750 Mev*

John I. Shonle
Lawrence Radiation Laboratory, University of California, Berkeley, California
(Received July 22, 1960)

The total π^--p cross section shows two well-defined peaks, one at 600 Mev and one at 890 Mev (laboratory-system kinetic energy).[1] Peierls[2] has assigned $D_{3/2}$ and $F_{5/2}$, respectively, for the orbital and total angular momentum states based on the photoproduction angular distributions[3] and polarizations of the recoil protons.[4] Landovitz and Marshall[5] suggest that $P_{3/2}$ and $D_{3/2}$ or $D_{5/2}$ assignments are also consistent with the data. Previous π^--p elastic scattering experiments have been made at 425,[6] 460,[7] 600,[7] 770,[7] 810,[8] 925,[9] and 950[10] Mev. These experiments have not led to any definite conclusions, partly because of large energy spreads and low statistics.

This experiment was conceived to try to establish the angular momentum at the peaks from elastic scattering on hydrogen. Negative pions at 610±20, 655±20, and 750±20 Mev were passed through a 30-inch propane bubble chamber operated in a 13-kgauss field.[11] The pions were focused, deflected, and collimated to give a momentum spread of ±1.5%. The energy spread quoted above comes from energy loss in the chamber. The mean beam momentum was checked by wire orbiting, by measuring the curvature of beam tracks in the bubble chamber, and from kinematics of elastic scattering events with stopping protons. All three methods gave consistent results. Twenty percent of the film was scanned twice. All events were measured on digitized microscopes (most of them on a "Franckenstein") and the data reduced on an IBM 650. A kinematics program gave the events a χ^2 test for elasticity using configuration-dependent errors. Good agreement with the expected χ^2 distribution was found. About 40% of the measured events were elastic.

Tracks entering the scanning region were counted in 4% of the pictures. Corrections were made based on calculated muon contaminations (11.5%) and measured electron contaminations (about 3%), and for interactions reducing track length. The resulting track lengths were checked by counting interactions and checking with the π^--p [1] and π^--C^{12} total cross sections.

The numbers of elastic scattering events found were 539, 1159, and 1008 at 610, 655, and 750 Mev, respectively. Analysis of about 20% more events is still in process, and corrections were made for these assuming they were randomly distributed. Corrections were made for scanning efficiency and azimuthal bias, but not as a function of scattering angle. A correction was made for carbon contamination (about 7%) by using the behavior of the nonelastic tail of the observed χ^2 distribution. For the total elastic scattering cross sections, corrections for small-angle scattering events which were missed were made by extrapolating the angular distributions to 0 deg. The resulting total elastic scattering cross sections are 16.6 ± 2.2 mb, 16.1 ± 1.6 mb, and 14.4 ± 1.3 mb, at 610, 655, and 750 Mev, respectively. The errors in the cross sections are thought to be about standard deviations, and are not strongly correlated from one energy to another. These results are compared with the results of other workers in Fig. 1. If the latest total cross sections[1] are valid, then the results at 810 and 950 Mev should possibly be scaled to where the crosses indicate. Within the errors shown, almost any energy dependence from one with peaks at 600 and 890 Mev to one which increases linearly may be concluded.

The angular distributions are shown in Fig. 2. The crosses indicate the expected forward scattering calculated from the optical theorem and dispersion relations.[13] The extrapolations of the observed angular distributions to 0 deg are compatible with these points if the cross sections are rising at small angles as a diffraction pattern with reasonable values of the radius. Fits of cosine power series were made to the data. In each case the intervals $0.9 \leq \cos\theta^* \leq 1.0$ were not considered, and only statistical errors were used, since other errors affect only the over-all normalization. Fits were made with the data divided into intervals of $\Delta(\cos\theta^*) = 0.05$ (38 points) and $\Delta(\cos\theta^*) = 0.10$ (19 points). The two fits agreed within errors with each other. The 19-point fits are given in Table I. The values of χ^2 reached plateaus at the powers of cosine shown. In all cases the coefficient of the next higher power of cosine was zero within the errors. The errors quoted have the normalization errors folded back in.

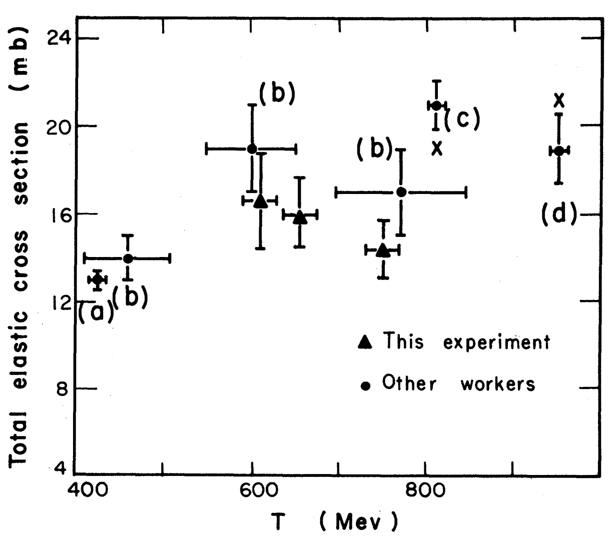

FIG. 1. The total elastic scattering cross section is given as a function of the pion kinetic energy (laboratory system). The crosses show suggested changes in the elastic scattering data based on the latest total cross-section data. (a) Reference 6; (b) reference 7; (c) reference 8; (d) reference 10.

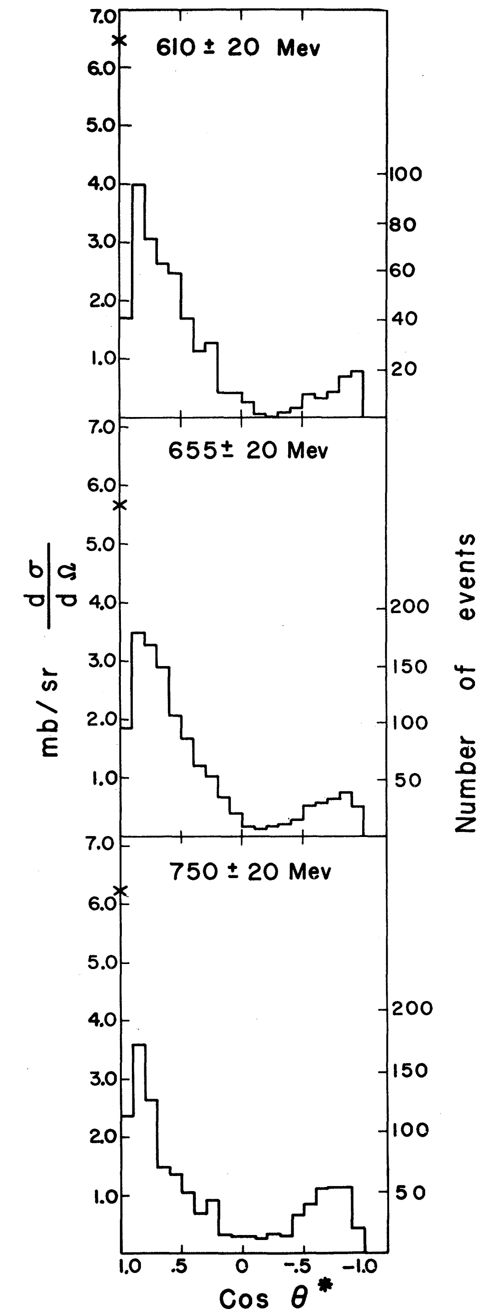

FIG. 2. The elastic scattering angular distributions are given as a function of the cosine of the angle in the center-of-momentum system. The crosses are the predicted forward scattering cross sections.

Table I. Coefficients of the various powers of $\cos\theta^*$ (in mb/sr) for the 19-point fits. The highest power and the value of χ^2 for the fit are given. There were $(18-n)$ degrees of freedom.

Energy (Mev)	n	χ^2	a_0	a_1	a_2	a_3	a_4	a_5
610	4	10.6	0.23 ± 0.04	1.73 ± 0.28	3.78 ± 0.61	0.27 ± 0.44	-1.23 ± 0.69	...
655	4	7.2	0.25 ± 0.04	1.56 ± 0.20	4.38 ± 0.50	0.17 ± 0.32	-2.54 ± 0.53	...
750	4	16.3	0.25 ± 0.04	0.81 ± 0.20	2.49 ± 0.48	-3.24 ± 1.02	0.52 ± 0.69	5.81 ± 1.22

The fact that a_2 and a_4 were found to be larger at 655 Mev than at 610 Mev should not be taken too seriously. It is assumed for what follows that a_2 is really at a maximum at 600 Mev. If the peaks in the cross section are resonances—that is, the real part of the phase shift goes through 90 deg—then the size of σ_{elas} compared to $\frac{1}{2}\pi(2J+1)\lambda^2|e^{2i\delta}-1|^2$ makes it likely that the first peak has $J \leq 3/2$ and the second $J \leq 5/2$. That the coefficient a_2 goes through a maximum at 600 Mev implies that the angular momentum state there is $J=3/2$. The decrease in a_2 and a_3 and the increase in a_4 and a_5 all imply that the next peak should have $J=5/2$. If it is assumed that both resonances go through +90 deg and that there is a reasonable energy dependence of the phase shifts, then even relative parity for the two resonances would lead to interference terms that would give negative contributions to a_2 and positive to a_4 around 600 Mev. It does not seem easy to reconcile such contributions with the observed coefficients. It would be difficult to explain a_2 and a_4 if one resonance goes through +90 deg and the other through -90 deg. Therefore it is most reasonable to assign odd relative parity to the resonances: $P_{3/2}$ and $D_{5/2}$, or $D_{3/2}$ and $F_{5/2}$. Thus the same possible angular momentum assignments are arrived at independently of the photoproduction data.

Several nonresonating states are needed to explain the observed angular distributions. Plausible sets of such other states have been constructed. The problem is underdetermined by the data at hand, since the phase shifts are complex. If some of these other states could be determined by other means, then the ambiguity of the orbital momentum of the resonances could possibly be eliminated. Because the nonresonant states are responsible for the negative value of a_4 around 600 Mev, its minimum is probably due to "accidental" cancellations. If the real part of the phase shift of the $J=3/2$ wave is 90 deg at 600 Mev, then the phase must have a large imaginary part. This conclusion is necessary to account for the observed amount of inelastic scattering when it is kept in mind that there must be some nonresonant elastic scattering. Strong absorption is in keeping with Peierls' conjecture[2] as to the cause of this peak. It should be emphasized that this experiment does not prove that the peaks are true resonances. However, it would be more difficult to account for the data without that hypothesis.

Isospin has been ignored in this qualitative analysis. One difficulty with this analysis is that a_3 and a_5 seem to be changing faster than general considerations would indicate likely. Part of the apparent sudden change may be due to a lack of sensitivity to the fifth and sixth powers of cosine at the lower energies. The supposition of insensitivity is compatible with the results of Goodwin et al.,[6] who find a best fit with a sixth-degree polynomial at 425 Mev.

The support of Dr. Wilson Powell is gratefully acknowledged. Dr. Oreste Piccioni, Dr. William Fowler, and Dr. Robert Birge helped immensely with the early stages of this experiment. We would like to thank Dr. Edward Lofgren and the Bevatron crew for their help and skill in beam sharing, and Larry Oswald and the bubble chamber crew for chamber operations. Jack Hohenstein did much of the scanning and has been indispensible in helping to compile the data. Edith Goodwin and Herbert Holden also helped with the scanning. Howard White and his staff are thanked for the data reduction. The author has consulted frequently with Peter Newcomb.

*Work performed under auspices of the U. S. Atomic Energy Commission.

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SENSITIVITY OF LOW-ENERGY PION-NUCLEON SCATTERING TO A PION-PION RESONANCE

S. C. Frautschi*
Department of Physics, University of California, Berkeley, California
(Received July 26, 1960)

Recently attention has been called to the possibility of explaining nucleon electromagnetic structure quantitatively by the introduction of a pion-pion resonance in the $T=1$, $J=1$ state.[1] Such a resonance should also affect pion-nucleon scattering. General expressions relating pion-nucleon to π-π scattering within the framework of double dispersion relations have been developed,[2,3] and some detailed applications have been made to low-energy π-N scattering.[4,5] In particular, it has been found that the $P_{3/2,\,3/2}$ π-N resonance is insensitive to π-π scattering.[4,5] However, the applications made to date have not been entirely satisfactory because the short-range π-N interaction is not well understood.

In this Letter we wish to point out that in π-N scattering the $J=1/2$, P states are extremely sensitive to the π-π resonance. The π-π contribution to these states near threshold is greater than the contribution to the $P_{T=3/2,\,J=3/2}$ state, roughly in the ratio[6]

$$P_{1/2,1/2}:P_{3/2,1/2}:P_{1/2,3/2}:P_{3/2,3/2}\sim 9:-4.5:-2:1.$$

We further wish to argue that the π-π resonance parameters which fit the nucleon electromagnetic structure make it difficult to obtain agreement with experiment in several π-N scattering states. This conclusion is especially strong in the $P_{1/2,1/2}$ state where, in addition to being large, the π-π contribution represents an attractive, long-range interaction which should lead to a large positive phase shift no matter what form the unknown short-range interaction may take.

Let us consider the $J=1/2$, P-state amplitude,

$$f_{J=1/2}^{\;P}(W)\equiv(q/\mu)^{-3}e^{i\delta}\sin\delta, \tag{1}$$

where W and q are the total energy and the pion momentum in the center-of-mass system. In Table I we list the contribution to f at threshold

Table I. Comparison of Chew-Low theory, and Frazer-Fulco π-π resonance contribution, with π-N scattering experiments for the $J=1/2$, P amplitudes f [Eq. (1)] at threshold. The experimental numbers are from the 1958 CERN conference.[a]

	Chew-Low	π-π	Total	Exp.
$f_{1/2}^{\;P}(T=1/2)$	-0.14	+0.41	+0.27	-0.038 ±0.038
$f_{1/2}^{\;P}(T=3/2)$	-0.035	-0.21	-0.245	-0.044 ±0.005

[a]1958 Annual International Conference on High-Energy Physics at CERN, edited by B. Ferretti (CERN Scientific Information Service, Geneva, 1958).