# Test of Hadronic Charge Symmetry by Pion Scattering on Deuterium

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A sensitive test of hadronic charge symmetry has been made by comparing differential cross sections for $\pi^+$ and $\pi^-$ elastic scattering from deuterium at 143 MeV. Coulomb effects were calculated with the three-body Faddeev formalism. After corrections for Coulomb effects the cross-section ratio indicates that charge symmetry is valid to within (0.4± 0.5)%.

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The comparison of $\pi^+d$ and $\pi^-d$ differential cross sections is a very sensitive test of nuclear charge symmetry. After removal of electromagnetic effects both total and differential $\pi^\pm d$ cross sections should be equal if charge symmetry is valid. Pedroni *et al.*[1] have made measurements of $\pi^\pm d$ total cross sections from 70 to 370 MeV which indicated possible charge-symmetry violations at the 3% to 8% level. These differences between $\pi^+d$ and $\pi^-d$ total cross sections persisted after Coulomb and Coulomb-nuclear interference corrections and after corrections similar to those calculated by Myhrer and Pilkuhn[2] caused by mass and width differences among the charge components of the $\Delta_{33}$ isobar.

Charge symmetry implies that the nuclear interaction is invariant under the inversion of the $T_3$ component of the isospin of every element of the system. Low-energy determinations of *nn* and *pp* scattering lengths,[3] $a_{nn}$ and $a_{pp}$, have large Coulomb corrections and the nucleon-nucleon asymmetry parameter $A_N = (a_{nn}{}^2 - a_{pp}{}^2)/(a_{nn}{}^2 + a_{pp}{}^2) = -0.05 \pm 0.20$ allows for charge-symmetry violations on the order of 10%. The binding energies of mirror nuclei such as $^3$H and $^3$He provide a better, but indirect, test of charge symmetry. Disagreements between measured[4,5] and calculated[6] binding energies allow a (1–5)% asymmetry between *nn* and *pp* forces.

The intermediate-energy $\pi d$ system is much better suited for testing charge symmetry in that Coulomb corrections are smaller, both the $\pi^+d$ system and its isospin-inverted $\pi^-d$ companion are now readily available to experimentalists, and differences between $\pi^+p$ and $\pi^+n$ (or $\pi^-p$ and $\pi^-n$) cross sections are large.

We measured $\pi^+d$ and $\pi^-d$ differential cross sections at a pion energy of 143 MeV to match the energy at which the maximum asymmetry in the total cross section was observed.[1] It was also at this energy that $\pi^\pm p$ differential cross sections were measured by Bussey *et al.*[7] and these together with the phase-shift analysis of Carter, Bugg, and Carter (CBC)[8] were used to obtain the absolute normalization for the $\pi d$ measurements. The $\pi N$ cross sections were calculated with the SCATPI[9] computer code which incorporates the CBC phase shifts.

The experiment was performed at the energetic pion channel and spectrometer (EPICS) of the Clinton P. Anderson Meson Physics Facility (LAMPF). The incident pion energy was 143 MeV (245 MeV/*c*) and the full momentum acceptance (±1%) of the channel was used for all data runs. The targets were $CD_2$ (194 mg/cm$^2$), $CH_2$ (152.7 mg/cm$^2$), and C (131.5 mg/cm$^2$). Each target was approximately $15\times23$ cm$^2$ (larger than the nominal beam size of $10\times20$ cm$^2$) and uniform in thickness to better than 1% over the entire target area. The deuterium isotopic purity of the $CD_2$ target was greater than 99%.

Data were measured at laboratory angles between 22° and 120°. At forward scattering angles the spectrometer angle was chosen to minimize the interference of elastic $\pi d$ scattering with inelastic pion scattering from $^{12}$C. At intermediate and back angles the spectrometer angle was chosen to agree with the existing $\pi^\pm p$ data of Bussey *et al.*[7] near 143 MeV. Additional $\pi p$ and $\pi d$ measurements were made at corresponding angles for which the momentum transfer was the same. The target angle was always set to half the spectrometer angle. The resolution of 400 keV full width at half maximum was dominated by the angular resolution and the effects of scattering chamber exit and spectrometer entrance windows. A 3° angular acceptance was used for data analysis.

At each angle, data were collected for each of the targets and then the magnets were reversed in polarity, cycled, and data collected for pions of the opposite sign. Spectrometer acceptance was folded out by changing magnetic fields for $\pi p$ and $\pi d$ measurements so that the elastic peak was always at the same position on the focal plane. Data collected with the C target were subtracted from both $CH_2$ and $CD_2$ data to eliminate interference of inelastic states in carbon with the $\pi p$ and $\pi d$ peaks.

Our $\pi^+d$ differential cross sections agree very well with the three-body calculations of Giraud, Fayard, and Lamot[10] and with the $\pi^+d$ measurements of Gabathuler *et al.*[11] There have been no previous measurements of $\pi^-d$ differential cross sections in this energy region except for the bubble-chamber measurements of Pewitt *et al.*[12] Our $\pi^+d$ and $\pi^-d$ differential cross sections will appear in a later publication.

We present in this Letter the ratio of the difference of $\pi^-d$ and $\pi^+d$ cross sections to the sum, defined as $A_\pi = [d\sigma(\pi^-) - d\sigma(\pi^+)]/[d\sigma(\pi^-) + d\sigma(\pi^+)]$. This ratio removes target thickness uncertainties and pion decay corrections and reduces uncertainties due to $\pi p$ phase shifts, wire chamber efficiencies, and scintillator dead times. The $\pi p$ normalization removed the need for an absolute flux determination and cancelled effects due to $\mu$ and $e$ contamination in the beam as well as minimizing effects of spectrometer solid angle acceptance, chamber efficiencies, and dead times. The resultant uncertainties in the ratio $A_\pi$ are due almost exclusively to statistics and to some residual uncertainty in the $\pi^\pm p$ normalization.

Our ratio data are shown in Fig. 1, where the percentage by which $A_\pi$ differs from zero is plotted as a function of center-of-mass angle. The errors shown include only statistical uncertainties in the foreground, background, and absolute normalization. The $\pi p$ phase shifts used for absolute normalization are from Carter, Bugg, and Carter.[8] The quoted[9] reliability of these phase shifts is 2% and 3% for $\pi^+p$ and $\pi^-p$ differential cross sections individually. The use of the actual $\pi^\pm p$ data measured by Bussey *et al.*[7] changes the $A_\pi$ data points by less than 0.5% and in a random manner, indicating that the ratio of the CBC cross sections is known to greater accuracy than are the individual cross sections. The use of the $\pi^\pm p$ phase shifts of Rowe, Salomon, and Landau[13] would lower the back-angle points (≥100°) by about 1.5% but these phase shifts do not reproduce the Bussey $\pi^-p$ back-angle data as well as do the CBC phase shifts.

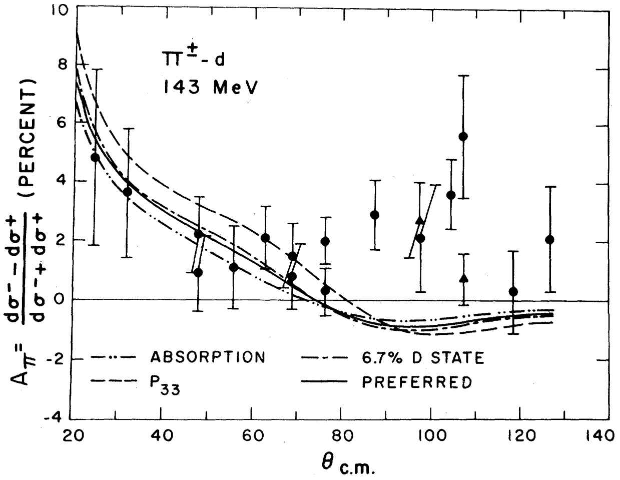

FIG. 1. The $A_\pi$ data represent the percentage difference between $\pi^-d$ and $\pi^+d$ elastic scattering differential cross sections divided by the sum. Errors are statistical. Data points indicated by triangles are from measurements made at a later time. No Coulomb corrections have been made. The theoretical curves represent the purely Coulomb differences expected between $\pi^\pm d$ cross sections for various sets of three-body $\pi d$ phase shifts. The "preferred" set includes all $S$ and $P$ wave $\pi N$ amplitudes, the 4% $D$ state in the deuteron, and no absorption. The "6.7% $D$ state" and "absorption" sets change the preferred set by including the 6.7% $D$ state in the deuteron and pion absorption, respectively, while the "$P_{33}$" set includes only the $P_{33}$ $\pi N$ amplitude. All calculations assume charge symmetry.

The data shown have not been corrected for any Coulomb effects. Instead these effects were incorporated into three-body Faddeev $\pi d$ calculations which otherwise explicitly assume charge symmetry. Thomas[14] has explicitly expressed the $\pi d$ cross sections in terms of strong, Coulomb, and Coulomb-nuclear interference contributions. This decomposition was applied to several sets of $\pi d$ amplitudes to determine the Coulomb effects on $A_\pi$. The resulting theoretical $A_\pi$ values in $\pi^\pm d$ cross sections are also plotted in Fig. 1. The "preferred" calculation includes all $\pi N$ $S$ and $P$ waves, a realistic deuteron wave function with a 4% $D$ state, and no "true" pion absorption. The effects of including separately only the $P_{33}$ $\pi N$ amplitude, a 6.7% deuteron $D$ state, or "true" pion absorption are shown in the other curves. Even the somewhat unrealistic curve with only $P_{33}$ $\pi N$ amplitudes lies close to the envelope of the other curves and the band of these calculations indicates that the Coulomb effects are quite insensitive to the particular $\pi d$ model used.

The agreement of the data with the envelope of three-body calculations indicates the extend to which charge symmetry is conserved in this interaction. An integral was obtained under the curve formed by the difference between the $A_\pi$ data points and the preferred calculation weighted by $2\pi \sin\theta$ and the average (for $\pi^+$ and $\pi^-$) differential cross section at that angle. This integral was divided by the average total elastic cross section (47 mb) to give a deviation from charge symmetry of $(0.4 \pm 0.5)\%$ where the error quoted includes both statistical and systematic uncertainties. Only in the region from 90° to 110° do the data have a statistically significant deviation from symmetry. The contribution from data between 90° and 110° to the asymmetry is about 0.3%. We have no explanation for a deviation in this particular angular range.

Pedroni *et al.*[1] observed a charge-symmetry deviation in $\pi^\pm d$ total cross sections at this energy of approximately 3% in the direction of negative $A_\pi$ in Fig. 1. This would correspond to a lowering of each data point by 3.4% if the charge-symmetry breaking were the same at every angle and divided among all reaction channels in proportion to their cross sections. Under these assumptions the Pedroni data would correspond to points lying 1 and 2 standard deviations below even our forward-angle data points with the largest error bars. It is unlikely that the deviation observed by Pedroni *et al.* lies exclusively in the region forward of 20° as the calculated Coulomb effects agree well with our data and a 20% effect would be required. If the deviation observed by Pedroni *et al.* were to lie exclusively in the region greater than 80°, our data would have to be in the −20% to −30% region to be consistent. It is therefore very unlikely that the deviation from charge symmetry seen by Pedroni will be reflected in back-angle $A_\pi$ data.

Our data are therefore consistent with charge-symmetry conservation at the 99.6% level in $\pi^\pm d$ elastic scattering. Charge-symmetry breaking is still possible in inelastic channels available to the $\pi d$ system. Miller,[15] however, has suggested that if the fundamental mechanism involved is the $\pi N$ interaction, then, in order to reproduce the energy dependence of the $\pi^\pm d$ total cross-section observations, any symmetry breaking should be reflected equally in all $\pi d$ channels, including the elastic channel.

Additional $\pi^\pm d$ elastic cross-section measurements are now in progress at 256 MeV where the total cross-section measurements[1] indicate that the charge-symmetry–breaking effect could be as large as 8% and of sign opposite to that at 143 MeV. A more complete treatment of the experimental and theoretical methods involved will appear in a later publication.

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